RETURN TO PLANNING
AND RESEARCH

HIGHWAY RESEARCH REPORT

CALIBRATION STANDARDS FOR NUC

(DENSI

INTE

69-25
DND

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 632908-1

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads November, 1969

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

November, 1969

Interim Report
M&R 632908-1
F-4-22

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

CALIBRATION STANDARDS

FOR

NUCLEAR GAGES

(Density Standards)

TRAVIS SMITH
Principal Investigator

E. C. SHIRLEY
Co-Investigator

R. E. SMITH, F. C. CHAMPION, D. J. HINRICHS
Analysis and Report

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Smith, Travis, Shirley, E. C., Smith, R. E., "Calibration Standards for Nuclear Gages (Density Standards)," State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report No. M & R 632908-1, November, 1969.

ABSTRACT: The background of calibration research for nuclear soil density gages is summarized. The physical and mineral descriptions of the master density reference standards developed by the California Division of Highways are presented. Fabrication and testing details are discussed; and test data from three gages of different manufacture on the standards are given. It is concluded that it is practical to fabricate density standards, and that the calibration curve developed on them can be used for most common California soils. The use of the master standards, and supplementary standards in the districts, is expected to increase the uniformity and accuracy of calibration of the nuclear instruments.

KEY WORDS: Soils, compaction control, nuclear applications, nuclear moisture - density determinations, nuclear testing, calibration, standards, evaluation, testing equipment.

ACKNOWLEDGMENTS

Recognition is extended to those technicians who performed most of the actual work on the project, particularly C. T. Gipson who was responsible for the fabrication of the original master density standards.

This is an interim report on work done under the HPR Work Program as Item No. F-4-22 in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads.

The opinions, findings, and conclusions expressed in this publication are those of the authors, and not necessarily those of the Bureau of Public Roads.

TABLE OF CONTENTS

INTRODUCTION

The California Division of Highways, beginning in 1954, has investigated the use of nuclear gages for determining soil moisture and density. Several formal research studies were conducted by the Materials and Research Department. As a result of these investigations, the Division now designates nuclear testing in its Materials Testing Manual as a method for ascertaining soil moisture and density in earth embankment construction control.

Determination of soil moisture and density with nuclear gages is an indirect method of testing. Electronic equipment is used to measure the radiation returned from a soil, during irradiation by a source contained in the gage. The amount of radiation returned is proportional to the density or moisture content of the soil. This requires that the units be calibrated by some means prior to their use. Recalibration may be required when a gage is repaired, a major component is replaced; or when electronic drift occurs within the gage. It is also necessary to periodically check the calibration of a unit, even without change in its performance.

Usually the gage manufacturers will supply calibration curves. The use of these has been generally unsatisfactory due to lack of means for reference, and in some cases, incorrect calibration. Most gages have also been calibrated (by the users) by correlation of nuclear results with sand volume tests, and/or soil compacted in large molds. Correlation with sand volume densities is undesirable due to the variability of the sand volume method, and the usual lack of a sufficient range of field densities. Volumetric soil molds are not desirable as an absolute means of calibration due to possible nonuniformity of material, and limited range of densities. Also both methods are laborious and non-permanent. Another objection is that they do not provide a standard reference. That is, there is no assurance that the calibration will be uniformly acquired or duplicated over a period of time, and from one California Highway District to another.

For the effective use of nuclear gages in highway construction, it was thought that permanent means must be provided for external calibration of the units. Each California Highway District should have a set of moisture and density standards, which would, in turn, be referenced to a common or central set of master standards. To answer this need, the program to develop moisture and density standards was initiated as a state-financed research project in July, 1967. A subsequent proposal was made for conducting the research as a BPR participating project and approved in September, 1968.

The work performed under the research authorization, and discussed in this report, includes a survey of past research by California and others which has bearing on the calibration problem. A set of master density standards was developed, representing two chemical compositions -- calcareous and siliceous. These were tested and evaluated. Prototypes of standards suitable for California Highway District use were fabricated and tested. Also, soil samples compacted in large molds for associated research were tested. These data are presented, and a tentative evaluation is included in the discussion.

Replicas of the high and low density prototype district standards have recently been made, and are being evaluated. The knowledge gained in their use, procedures developed, etc., will be discussed in a subsequent report. The development of the moisture standards will also be reported separately.

CONCLUSIONS

1. Calibration standards can be satisfactorily fabricated of portland cement and selected aggregates. These are as stable and uniform as those cut from natural stone.

2. Even when exercising great care in fabrication, it is probable that there will be a variation of density within the standard of ± 1 to 2 lb per cu ft from the bulk density calculation for the block. This probable variation also exists in the natural stone standards.

3. Over the range of densities comprised by the California standards (93 to 170 lb per cu ft), the calibration appears to be slightly curvilinear when plotted on semi-logarithmic paper.

4. When testing a wide range of soils compacted in a large mold; it is estimated that the probable accuracy of the nuclear test (one standard deviation) is 2 to 2.5 lb per cu ft when using a calibration determined on the standards.

5. The basic calibration determined on the master density standards is satisfactory for use in construction control for the common California soils. Some adjustment may have to be made for specific gages when testing unusual materials.

6. The use of a high and low density standard in each of the Highway Districts, in conjunction with the master or central standards, should greatly improve the uniformity and accuracy of nuclear gage calibration within the state.

DISCUSSION

Problems in Gage Calibration

Calibration problems were initially encountered by the California Division of Highways with the use of a commercial backscatter type nuclear moisture and density gage in 1959-1961.* The gage, using the manufacturer's calibration, indicated densities up to 15 lb per cu ft heavier than those determined by the sand volume test (1). This was corrected by calibrating the gage on soil compacted in a large mold; a measure suggested by the gage vendor. During the

*The California Division of Highways used an early commercial nuclear gage to experimentally investigate changes in moisture and density on highway projects as early as 1954(1).

period 1961-1964, a number of reports were published by California and others, which indicated that individual calibration curves were required for various soil types. This meant, of course, that a set of permanent standards could not be used. It should be borne in mind that most of this work was done with the backscatter or surface type nuclear density gage.

Weber reported in testing soils on 10 construction projects, "....a calibration curve is required for each soil and that more than one calibration curve generally will be required for each construction project." (1, p. 68). Worona and Gunderman indicated that both soil type and gradation affected the correlation of the nuclear gage result with the sand-cone method (2). Ralston and Anday attempted to develop laboratory calibration curves for use in the field with different major soil types (3). They discovered in the laboratory phase of their investigation that surface texture was critical. In their field work they found that use of the laboratory developed curves indicated densities less than those indicated by conventional in-place density tests. It was concluded that calibration should be based on field data.

In 1964-65, laboratory research, conducted by the California Division of Highways, showed that the transmission type density test had a significant advantage over the backscatter test (4, p. 9). It was found that surface texture affected the conventional backscatter test profoundly, but had negligible effect on the transmission test at the deeper probe depths. This study also showed that collimation of emitted radiation improved the backscatter test, making it more sensitive to density, while reducing the effects of surface texture.

There are two primary reactions as gamma radiation passes through matter. One, called Compton scattering, is that of an incident gamma ray encountering an electron, to which it imparts a portion of its energy, and departing with lower energy and at a different angle. This occurs with radiation of higher energy, and is not appreciably affected by the chemical identification of the atom. The second reaction, called the photoelectric effect, is dominant for the lower energy gamma radiation. Here the energy of the ray is entirely absorbed by the atom, causing either release of an electron, or a rise in its energy level. The different elements vary greatly in their capacity to absorb radiation in this manner. This second phenomenon is believed to be the primary cause of the calibration problems with regard to soil type. As a consequence, much effort has been expended by several investigators in attempting to compensate for the chemical makeup of soils by maximizing the Compton effect and minimizing (or correcting for) the photoelectric reaction.

Kühn proposed a test method in which an air gap is introduced between the gage and material tested, and increased until the maximum count rate is observed (5). This height depends on the Compton or backscatter interaction, and theoretically should be a function of density rather than chemical composition. He indicated that the effect of roughness is eliminated by this technique; however, later California research showed that roughness affected a reading at optimum air gap as much as a flush reading (4, p. 66, 124). Preiss suggested that a nuclear gage should be designed on the Compton scattering process to minimize the absorption reaction, or chemical effect (6). His proposed arrangement of source and detector was such that the once or twice scattered photons constituted the major part of the count. This scheme minimizes the depth of penetration of the radiation, and the probability of absorption. However, California research had shown that collimation of the source, to promote maximum penetration of the soil by the radiation, resulted in superior accuracy and greatly minimized the effects of surface roughness (4, p. 28, 62). Also, experience with the Lane-Wells mobile unit showed that a backscatter arrangment using a collimated detector and source could effectively tell density on a variety of soils (7). This equipment used a single limestone block as a calibration reference.

Ballard and Gardner proposed that nonsoil standards of known chemical composition be used as a basic calibration. A mathematical correction would then be applied to compensate for the known or estimated chemical composition of a soil (8). They indicated that concrete standards were not satisfactory as calibration references. Williamson and Witczak published the experience of the Indiana Highway Department with the backscatter type of portable instrument (9). They found that distinct parallel curves existed for coarse and fine grained material. The use of a soil's pH to indicate mineral composition was discussed. It was suggested that a family of field calibration curves be developed based on gradation and soil pH. Todor and Gartner (Florida) reported that using the direct transmission principle seemed to eliminate the necessity for individual calibration curves (10). However, it was necessary to shift the curve (determined in the laboratory using soil compacted in a mold) approximately 2 lb per cu ft to correlate with a water balloon type field density test. Anday and Hughes suggest that the whole problem of soil type can be avoided by use of direct comparison between a control strip and the test site. (11). They state that any calibration can be used, providing it is sufficiently sensitive.*

In 1965-1967, California conducted a large scale field evaluation of the use of nuclear gages in actual construction control situations (12). The transmission type gage was found to be acceptable for this use. It was also found that a single calibration curve could be used for all soils when the deeper probe depths were employed. The commercial backscatter type gages, as used in the research, were not suitable for compaction control. It was recommended that permanent standards should be established, and that field calibration by correlation with in-place densities using the sand volume method, should be discouraged.

The Oklahoma Department of Highways reported the fabrication of standards for depth density gages using crushed stone and river gravel in a container (13). This provided three density calibration points for each standard; dry, flooded, and saturated. A compacted clay was also used to supplement these references. They report that the use of a combined calibration curve from these standards permits the determination of density within a band width (maximum) of $\pm$ 4.4 percent. Readings with the gage on the concrete reference standards used by the equipment manufacturer fell within these limits.

*The calibration curve must have a valid slope (relative change in counts versus density), as well as having sufficient sensitivity. Therefore, the basic problem is still present, even when using the test strip technique, i.e., providing reference standards for the calibration and checking of the nuclear gage.

In summary, the essential mechanism in determining density with a nuclear gage is that of the overall attenuation and absorption of gamma ray energy by the soil. This includes both the Compton and photoelectric reactions. The successful gage has a geometry which insures that the mean free path of gamma rays through the soil is long enough to achieve a high probability of the terminal radiation reaching the detector tube being proportional to density. The transmission type test at the deeper probe depths, or a modified backscatter test such as used by the Lane-Wells apparatus, fulfill this requirement. It then becomes practical to develop a set of reference standards for the purpose of gage calibration.

Criteria for Density Standards

One of the problems encountered in the design of density standards is choice of material. Some investigators have argued that standards should be made of artificial materials such as layered gypsum board, metals, and various chemical compounds in order to obtain better uniformity of density and chemical composition. However, for the purposes of the California Division of Highways, the master density standards should represent the compositional and density extremes found in local soils. Individual uniformity in density and composition is also important.

Of the possible soil constituents which may affect a nuclear density test, silica and calcium are most apt to be found in concentrated form at some locations within California.* Therefore, two sets of standards were designed. By making one of these sets predominantly siliceous in composition, and the other predominantly calcareous, the range of chemical composition of California soil should be encompassed. Since the chemical composition of soil is derived from the parent rock, it was believed at the time that the standards should be fabricated of natural stone where possible.

Three densities were desired for each set of standards. One density should be less than the minimum densities normally encountered in California soils, the second should be near the middle of the California soil density range, and the third should be greater than the maximum densities normally found in California soils.

The following criteria were established for the two sets of master density standards:

1. Each set should include the range of densities encountered with California soil (as outlined above).
2. All standards should be uniform and homogeneous with respect to chemical composition and density.
3. The standards must be sealed to prevent undue change in weight due to variation in moisture content after drying to equilibrium.

*At the present time, one location is using considerable quantities of a slag with high calcium content.

4. The configuration of the standards should effectively represent an infinite volume to the instrument. Previous experience and research have shown that a standard with dimensions of at least 18 in. x 18 in. x 12 in. substantially fulfills this criterion (4). (The master density standards measure approximately 18 in. x 22 in. x 16 in.)

Composition, Density of Master Standards

Samples of natural stone having the desired chemical composition were obtained from several locations throughout the state. Specific gravity tests were run to determine the bulk densities of the materials. Standards were then made from the stone having the required unit weights and chemical compositions. The standards cut from natural stone are:

1. Low density silica, S-1, 93 lb per cu ft (tuff)

2. High density silica, S-3, 165 lbs per cu ft (granite)

3. High density calcareous, C-3, 170 lbs per cu ft (marble)

Natural stone suitable for the remaining three blocks was not readily available, so they were cast of concrete made of portland cement and selected aggregates having the desired chemical composition. The aggregates were restricted in size to those passing a No. 4 sieve in order to more easily attain uniformity of density and mineral content. Specific gravity tests were conducted on potentially suitable aggregates to determine which could be used to obtain the densities sought. The standards cast of concrete were as follows:

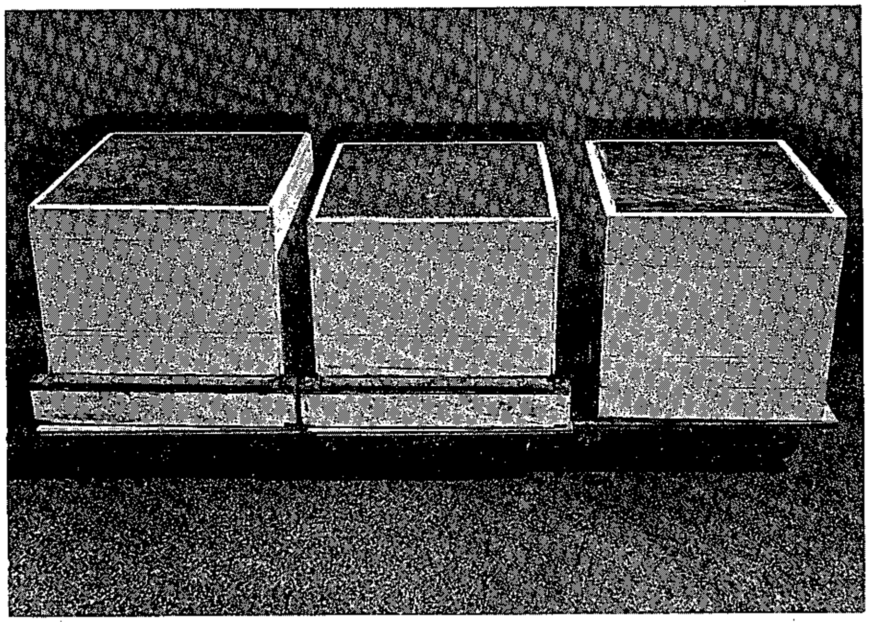
1. Low density calcareous, C-1, 102 lbs per cu ft (calcite - tufa)

2. Middle density calcareous, C-2, 135 lbs per cu ft (calcite)

3. Middle density silica, S-2, 127 lbs per cu ft (silica-sand)

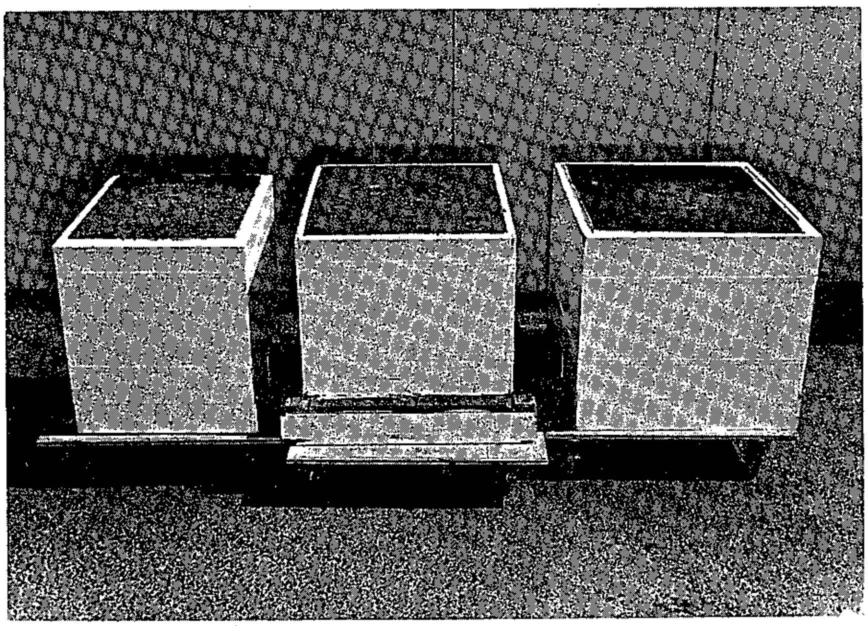
Mix designs for the standards are given in Table 1. See Photos 1 and 2 for the master standards.

PHOTO NO. 1



Finished Calcium Master Density Standards.

PHOTO NO. 2



Finished Silica Master Density Standards.

Table 1

Approximate Mix Design of Cast Standards

Material	Specific Gravity	% By Weight	% By Volume	Grading Range
Calcium Standard, C-1, Unit Weight = 102 lbs per cu ft				
Cement	3.15	26	14	
Water	1.00	12	21	
Air	-	0	8	
Calcite Sand	2.70	18	11	-#4 to +#50
Tufaceous Sand	1.60	44	46	-#4 to +#50
Calcium Standard, C-2, Unit Weight = 135 lbs per cu ft				
Cement	3.15	20	14	
Water	1.00	8	19	
Air	-	0	7	
Calcite Sand	2.70	72	60	-#4 to #50
Silica Standard, S-2, Unit Weight = 127 lbs per cu ft				
Cement	3.15	16	11	
Water	1.00	8	18	
Air	-	0	9	
Silica Sand	2.65	76	62	-#30 to +#50

Chemical Analysis of Master Standards

The general mineral compositions of the master standards are presented in Table 2. These compositions are estimates based on core samples taken from the master standards when drilling transmission holes. The quantities are given as oxides of the materials expected in the samples. Therefore, if the minerals are present as oxides other than those reported, these estimates may be in error.

Table 2

Master Density Standards
Mineral Composition Standards

Standard Number	Silica SiO_2	Alumina Al_2O_3	Calcium CaO	Magnesia MgO	Iron Fe_2O_3	Ignition Loss CO_2	Potassium % K
C-1	31.8	8.5	32.0	1.1	2.8	20.32	.25
C-2	4.5	1.6	54.0	0.6	0.9	37.72	.09
C-3	0.8	0.1	34.5	17.2	0.4	46.35	.01
S-1	70.7	13.7	1.45	1.1	2.5	1.26	.14
S-2	76.5	0.9	10.6	0.4	3.3	4.41	.07
S-3	64.0	17.6	4.3	1.9	4.0	1.14	.36

Composition, Density of Prototype District Standards

Next, the prototypes of the reference standards for District use were fabricated. Since these are to be used simply as calibration checks, there was no requirement concerning chemical composition. Two densities were desired which would be representative of the range commonly found in compacted California soils, and which would differ by 35 to 45 lbs per cu ft. This would insure that calibration curve verification with the reference standards would be less sensitive to minor testing discrepancies. With these two exceptions, the district prototypes were designed and built using the same criteria which governed the master standards. The first prototypes were rejected, because the resultant densities were unacceptable (one too low, the other too high). Also, the material used for their fabrication was from a rather uncommon origin, and it would be hard to duplicate these blocks. A third block was fabricated to obtain an additional calibration point for research purposes. These three prototypes are labled as the "T" blocks with densities of 93, 134 and 160 lbs per cu ft. Although these blocks were unacceptable as district prototypes, they have proved useful for additional points on the calibration curves.

After rejecting the above standards as district prototypes, two new blocks were fabricated, based on the same criteria, but using material that was more easily obtainable. The district prototypes are designated as P-1 and P-2 with densities of 112 and 152 lbs per cu ft, respectively. Since these blocks satisfied all criteria, a duplicate set of reference standards was made for each of the highway districts.

Physical Description of Master and Prototype District Standards

The dimensions of each standard were measured to the nearest .001 foot in three trials by three individuals. The volume of each standard was calculated from the average of the three sets of dimensions.

Using scales accurate to the nearest pound, the standards were weighed periodically until the weights appeared to stabilize. The blocks were then sealed. Weights obtained just prior to sealing of the blocks were used for the initial bulk density calculations, and later adjusted for change in weight due to additional water loss. Note that of the master standards, only the natural blocks, changed appreciably in weight. The changes were (over a 1-year period):

1. C-3, 173 to 170 lbs per cu ft.
2. S-1, 96 to 93 lbs per cu ft.
3. S-3, 168 to 165 lbs per cu ft.

The physical data for all of the standards are summarized on Table 3.

Table 3

Physical Properties of the Standards

Standard Number	Length (ft.)	Width (ft.)	Height (ft.)	Volume (ft.^{3})	Bulk Density pcf	Predominant Mineral Compound	Method of Fabrication
C-1	2.01	1.67	1.33	4.44	102	Calcite-tufa	Cast
C-2	2.01	1.68	1.26	4.26	135	Calcite	Cast
C-3	1.82	1.51	1.26	3.46	170	Marble	Natural
S-1	1.84	1.59	1.27	3.72	93	Tuff	Natural
S-2	1.83	1.50	1.31	3.60	127	Silica Sand	Cast
S-3	1.67	1.26	1.24	2.59	165	Granite	Natural
P-1	1.84	1.50	1.33	3.65	112	Expanded Shale	Cast
P-2	1.84	1.50	1.34	3.66	152	P.C.A. Sacramento*	Cast
T-1	1.84	1.49	1.34	3.66	93	Lava	Cast
T-2	1.84	1.49	1.33	3.66	160	Volcanic Ash	Cast
T-3	1.83	1.50	1.33	3.65	134	Schist	Cast

*P.C.A. Sacramento - typical river run aggregate consisting of volcanic, granitic, sandstone, and many other materials.

Fabrication Details, Preparation for Testing

The stone standards were cut to size and surfaced by a local monument company. The testing surfaces were finished plane and smooth.

The cast standards were fabricated by research personnel. Originally, there was some doubt as to whether or not uniformity in the concrete standards would be attainable. Due to the care taken in batching and mixing, however, it is felt that they are satisfactorily uniform. Since the concrete mixer was relatively small, 2.2 cubic feet maximum capacity, each standard had to be fabricated in two lifts. This may have helped uniformity as batching in 2 lifts tends to prevent a density gradient within the block, due to segregation of aggregates.

The top surfaces of the cast standards were not smooth. This would cause errors if nuclear readings were taken on these surfaces. Therefore, after three months of curing, the blocks were sent to a monument company for surfacing. It was extremely difficult to obtain a plane surface because the surfacing wheel tended to dig out aggregate particles. However, the bottom surface of the blocks, as cast, proved to be satisfactorily smooth for testing with the nuclear gages.

Once the desired surface was attained on both the natural and cast standards, two 3/4-in. holes were cored vertically through each block for the transmission type gages (Photo No. 3). The two holes were drilled so that the standards could be tested in two positions, and to permit their use with a variety of instruments, regardless of instrument configuration.

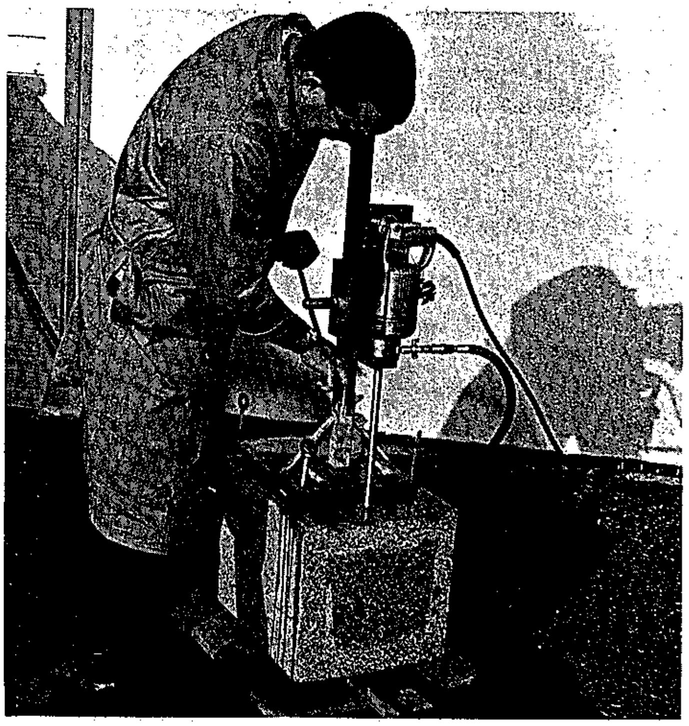
To help maintain density stability, the standards were coated with epoxy paint. The sealing of the blocks lessens the change of weight change due to climatic conditions (Photo No. 4). Once the standards were sealed, they were weighed again to determine the epoxy weight. This proved to be negligible. Readings were taken with the nuclear gages before and after sealing to check the effect of the epoxy coating on the nuclear test. No effect was detected. Stages of development are shown in Photo No. 5.

Protective wooden containers were built for the standards leaving only the top surface exposed. Each standard is mounted on a dolly to provide ease of movement to and from storage, and to facilitate separation of the standards when several gages are being operated simultaneously.

Testing Standards with Nuclear Gages

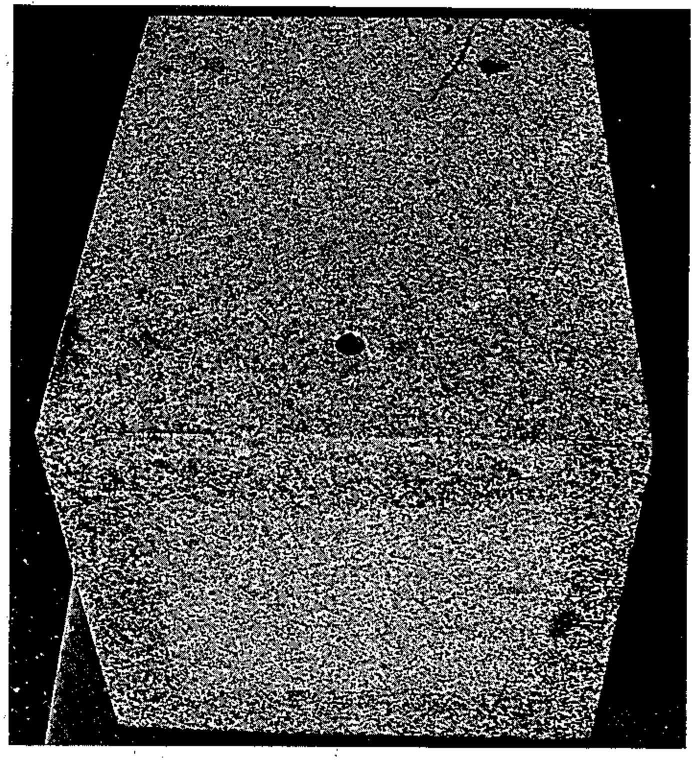
Throughout this project, certain basic procedures were followed to insure consistent results. The gages were warmed-up, by continuous counting for at least fifteen minutes, to reduce the possibility of error from unstable electronics. Gage standard counts were taken prior to, and periodically throughout, the test period. The standard count is used to check and compensate for minor electronic drift and to detect gage malfunction. Another control procedure followed was care in placement of the gage on the standard. The transmission hole in the standards has a slightly greater diameter than the transmission rod. As a consequence, the nuclear reading on a standard can vary with different positioning of the instrument. This can amount to as much as 6 lbs per cu ft on a standard of 127 lbs per cu ft. Therefore, greater reproducibility was achieved by always pulling the gage to the rear after inserting the transmission rod (See Photo No. 6).

PHOTO NO. 3



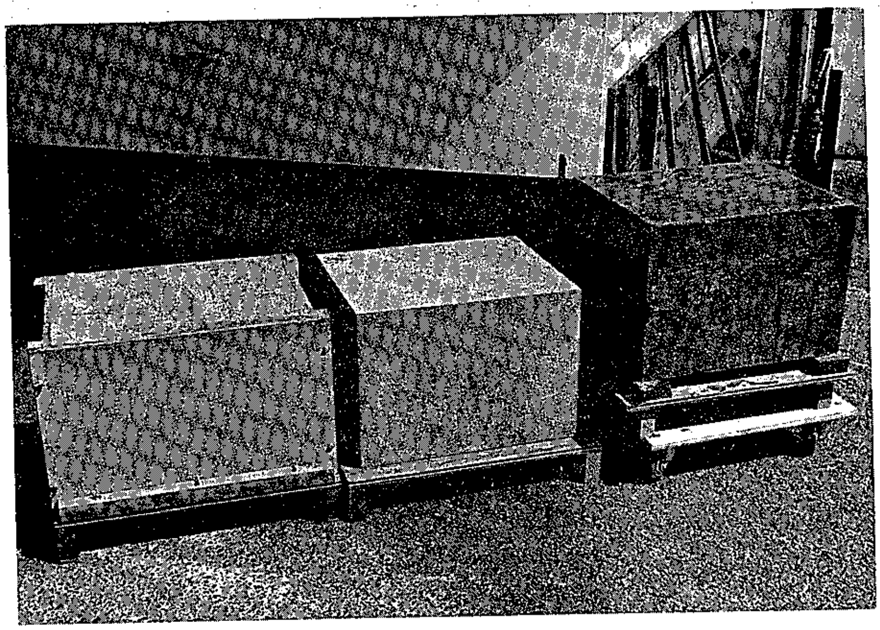
Drilling Transmission Holes in Standard.

PHOTO NO. 4



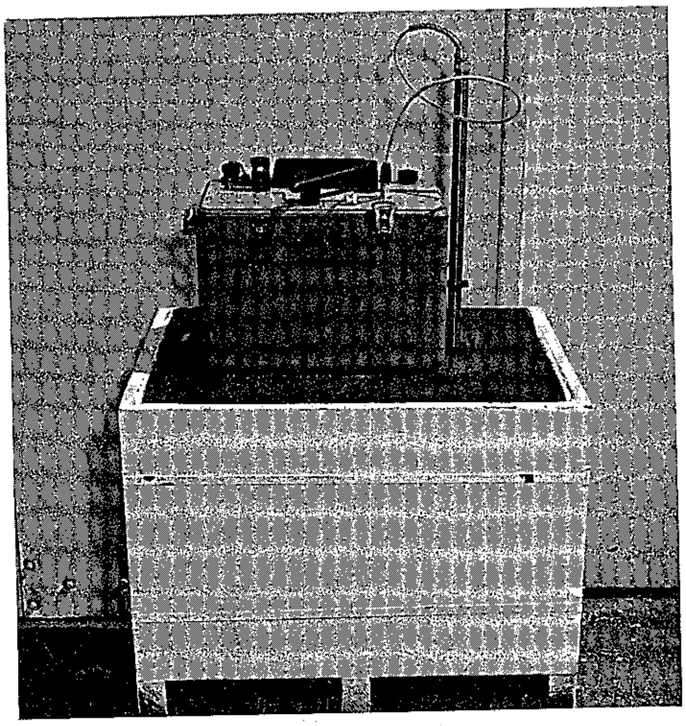
Holes Drilled, Block Ready For Sealing.

PHOTO NO. 5



Three Stages of Development, Left to Right:
1. Block in Forms. 2. Block Curing. 3. Block Sealed.

PHOTO NO. 6



Nuclear Gage in Transmission Test Position.

The three nuclear gages used for testing the density standards were:

1. Nuclear Chicago, Scaler Model No. 5920, probe No. 5901, with 4.5 mc radium-beryllium source. (Modified for transmission)

2. Troxler, Scaler Model No. 1603, probe No. 1401, with 3 mc radium-beryllium source. (Source in rod)

3. Portaprobe Model No. AM2 with a 10 mc Cesium 137 source, 50 mc Americium 241-Be.

The use of three different instruments provided a means of evaluating the effectiveness of the density standards when calibrating gages of various physical configurations and radioactive sources. Figures 1, 2 and 3 show calibration curves for each gage.

The overall response of the nuclear gage is that of a proportional loss of gamma ray energy with increase in soil density. The function can be approximated by the expression:

$$R = R_o\, e^{-u\rho}$$

Where:

R = radiation at detector

R_o = initial radiation

e = base of the natural logarithms

u = absorption coefficient (material property)

ρ = density

x = distance between source and detector

Since the distance between the source and detector is constant for a given test mode, it is convenient to represent it in its logarithmic form:

$$\log_e R = \log_e R_o - \mu \cdot \log_e e \cdot \rho$$

$$c_1 R = c_2 R_o - c_3 \cdot \rho$$

or:

$$R = c_4 R_o - c_5 \cdot \rho$$

which of course plots as a straight line on semi-logarithmic paper. This expression has usually given the best results in regression analysis of nuclear gage readings versus densities determined by other means.

However, it appears that, over the range of densities studied with the three different nuclear gages on the California calibration standards, the relationship is slightly curvilinear on a semi-logarithmic plot. This is probably to be expected, as the absorption factors are not constant, but vary with density. Rather than fit a continuous curve to the data, it has been found convenient to approximate the relationship by two straight lines of slightly different slopes

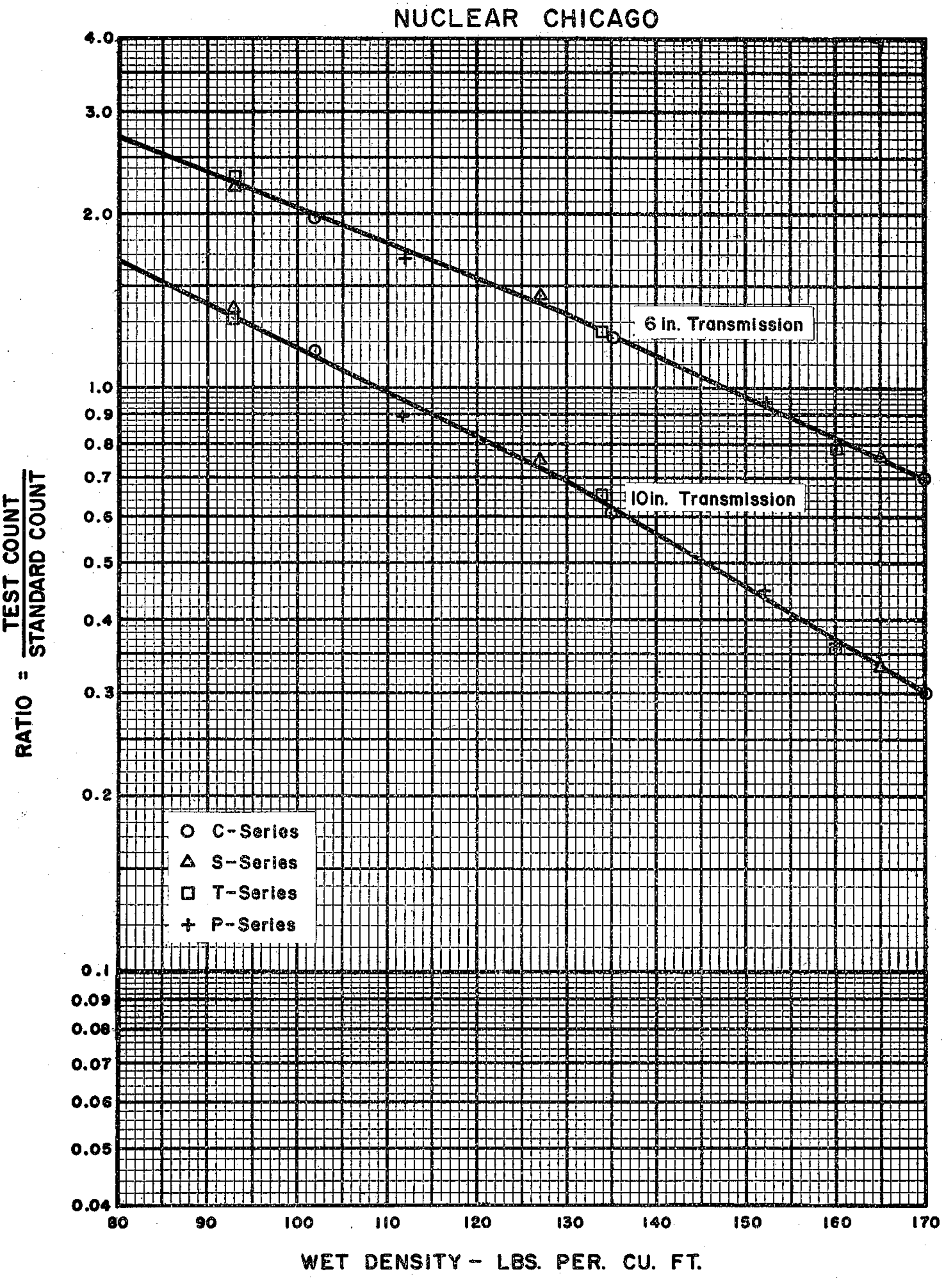

NUCLEAR CHICAGO
RATIO = TEST COUNT / STANDARD COUNT
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
80
90
100
110
120
130
140
150
160
170
WET DENSITY – LBS. PER. CU. FT.
6 in. Transmission
10in. Transmission
C-Series
S-Series
T-Series
P-Series

Figure 2

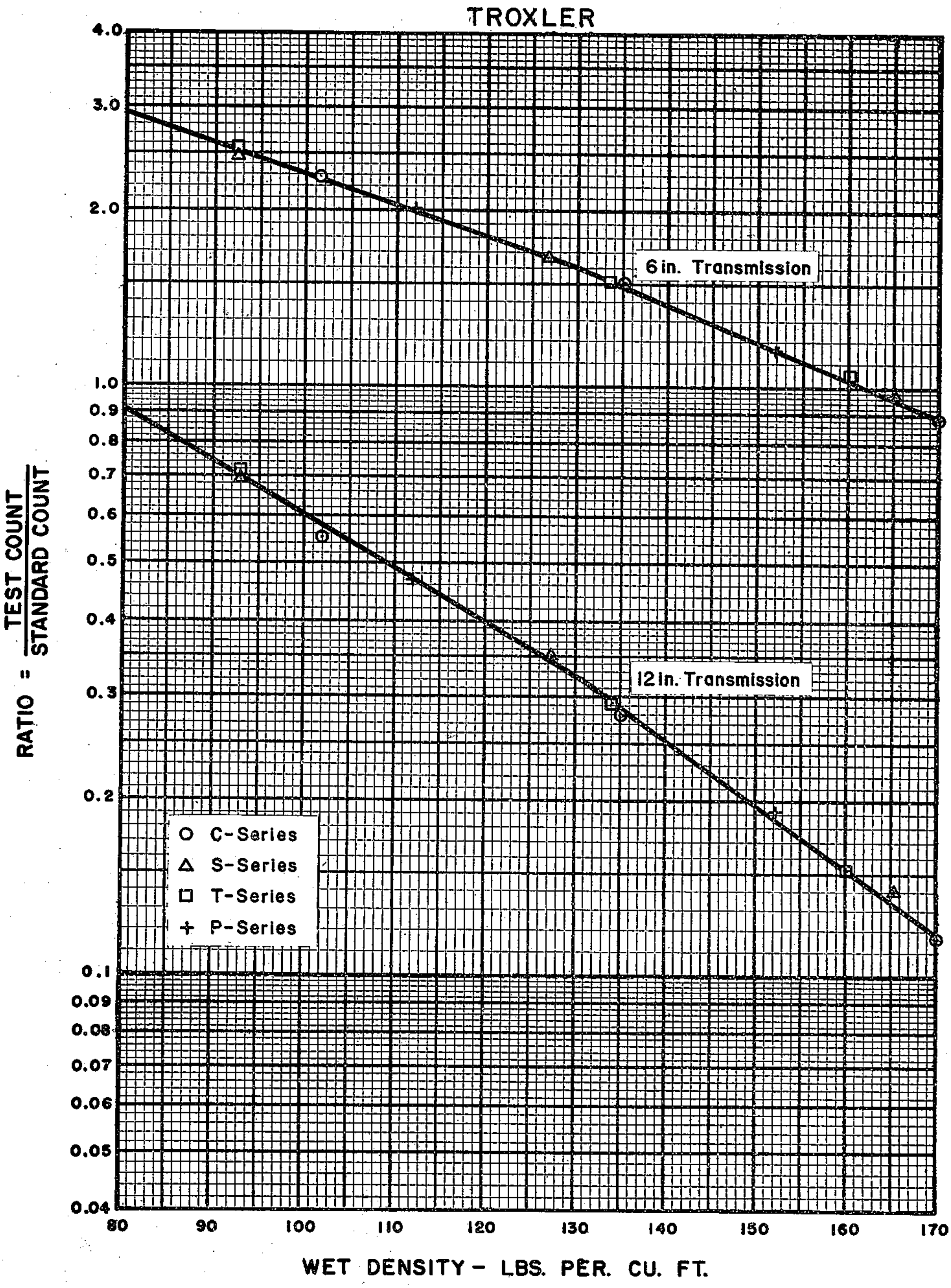
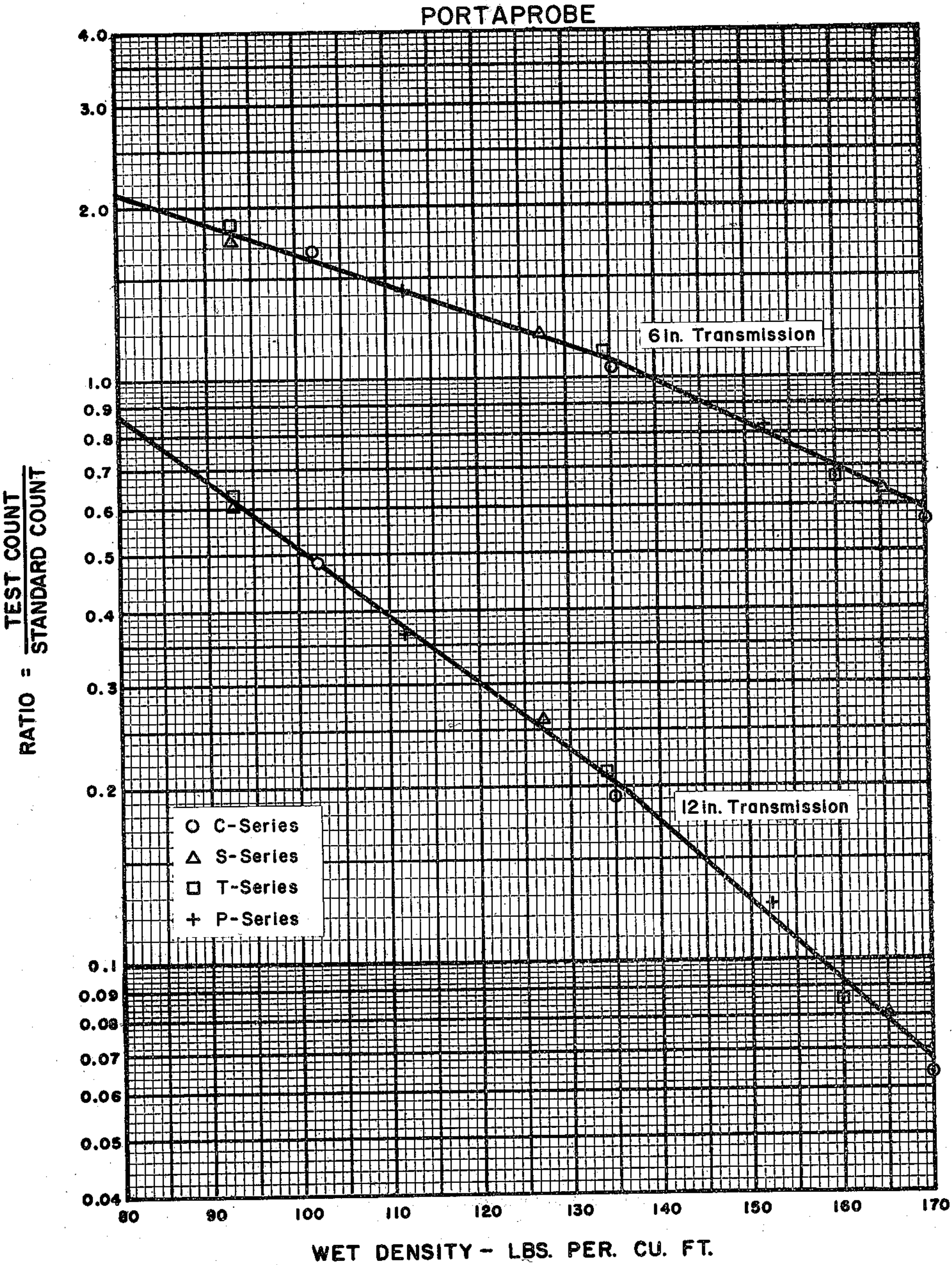

TROXLER
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
RATIO = TEST COUNT / STANDARD COUNT
6 in. Transmission
12 in. Transmission
C-Series
S-Series
T-Series
P-Series
80
90
100
110
120
130
140
150
160
170
WET DENSITY - LBS. PER. CU. FT.

Figure 3


PORTAPROBE
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
80
90
100
110
120
130
140
150
160
170
6 in. Transmission
12 in. Transmission
C-Series
S-Series
T-Series
P-Series
RATIO = TEST COUNT / STANDARD COUNT
WET DENSITY – LBS. PER. CU. FT.

meeting at 130 - 135 lbs per cu ft, Figures 1, 2, and 3. These calibration curves are obtained by visual best fit, and are not the result of regression analysis.

The variance, or scatter, observed in the data is considered to be representative of what may be expected with similar standards of differing materials and methods of fabrication. For example, there is a probable variation from point to point within the standards (both cast and natural) of $\pm$ 1 to 2 lb per cu ft from the bulk density used in plotting. Associated work with cast standards has shown a density gradient from top to bottom - even with the extreme care used in casting. And, there are differences in the way a particular gage responds to the composition, surfacing, the inclination of transmission holes, etc., of the individual blocks.

One of the first things noted about these calibration curves is the relative lack of chemical response for the three gages on the two series of standards. If parallel lines are drawn through the middle and high blocks of both sets (silica and calcareous), there is an offset between them of some 1 to 3 lb per cu ft, depending on the gage. If the same construction is made between the low and mid-density blocks, the lines either converge or cross.

The six basic standards, the C and S blocks, have been used for over a year in testing newly purchased gages for specification compliance. The gage specifications include requirements for both sensitivity to density, and maximum permissible chemical effect (14). For the 10 in. transmission test mode, it is required that there be less than a 4 lb per cu ft spread between calibration curves drawn through the siliceous and calcareous sets of standards. The backscatter test must exhibit less than 6 lb per cu ft spread.*

At the present time it appears that a properly designed gage can stay well within these limits. However, the early models of a gage offered for testing by one manufacturer had difficulty in passing this requirement in both the backscatter and transmission test positions. This was overcome by changing the gage geometry; and by using improved detector tubes which have only been recently available. These incorporate a lining which acts as a partial filter for the terminal low energy radiation reaching the detector.

Calibration on Standards vs. Large Compacted Soil Samples

A primary question, of course, is, "How does a calibration curve determined on these blocks work on soils?" This subject is being investigated at the time of writing of this report, and the findings are scheduled for publication in the final report. However, tests were made using some 24 individual samples of several different soil types which were compacted in large molds for another research project. Readings, taken on these with two nuclear gages, are shown plotted versus the calculated bulk density of the samples in Figures 4 and 5. Figure 4 is representative of data taken with the modified Nuclear Chicago instrument in the 6 and 10 in. transmission positions. Testing with the Portaprobe in the 6 and 12 in. transmission mode is shown by Figure 5. The solid line is that of the calibration established for the particular gage as was shown in Figures 1 and 3.

*Gages purchased by the California Division of Highways must be capable of testing in both the backscatter and transmission modes.

Figure 4

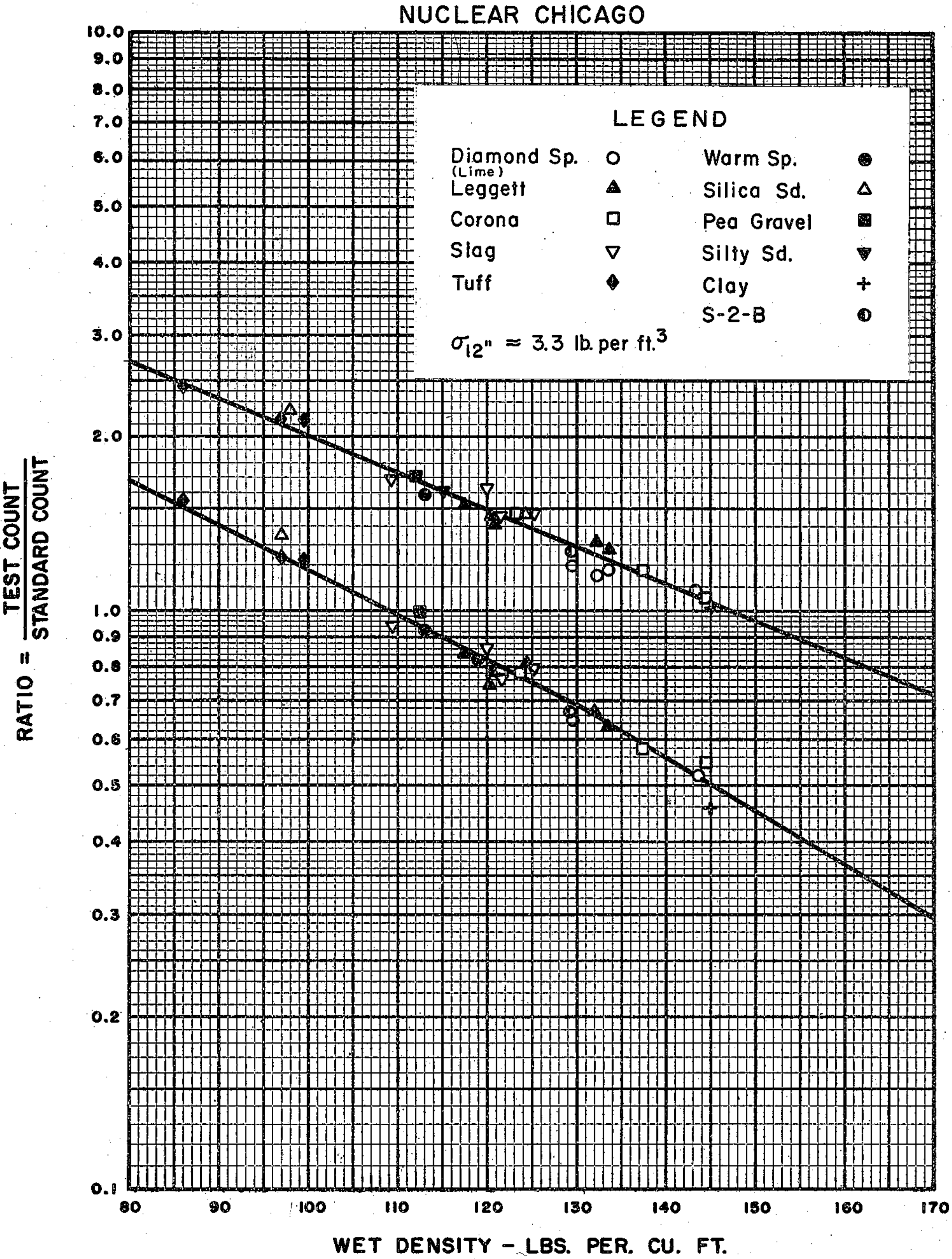
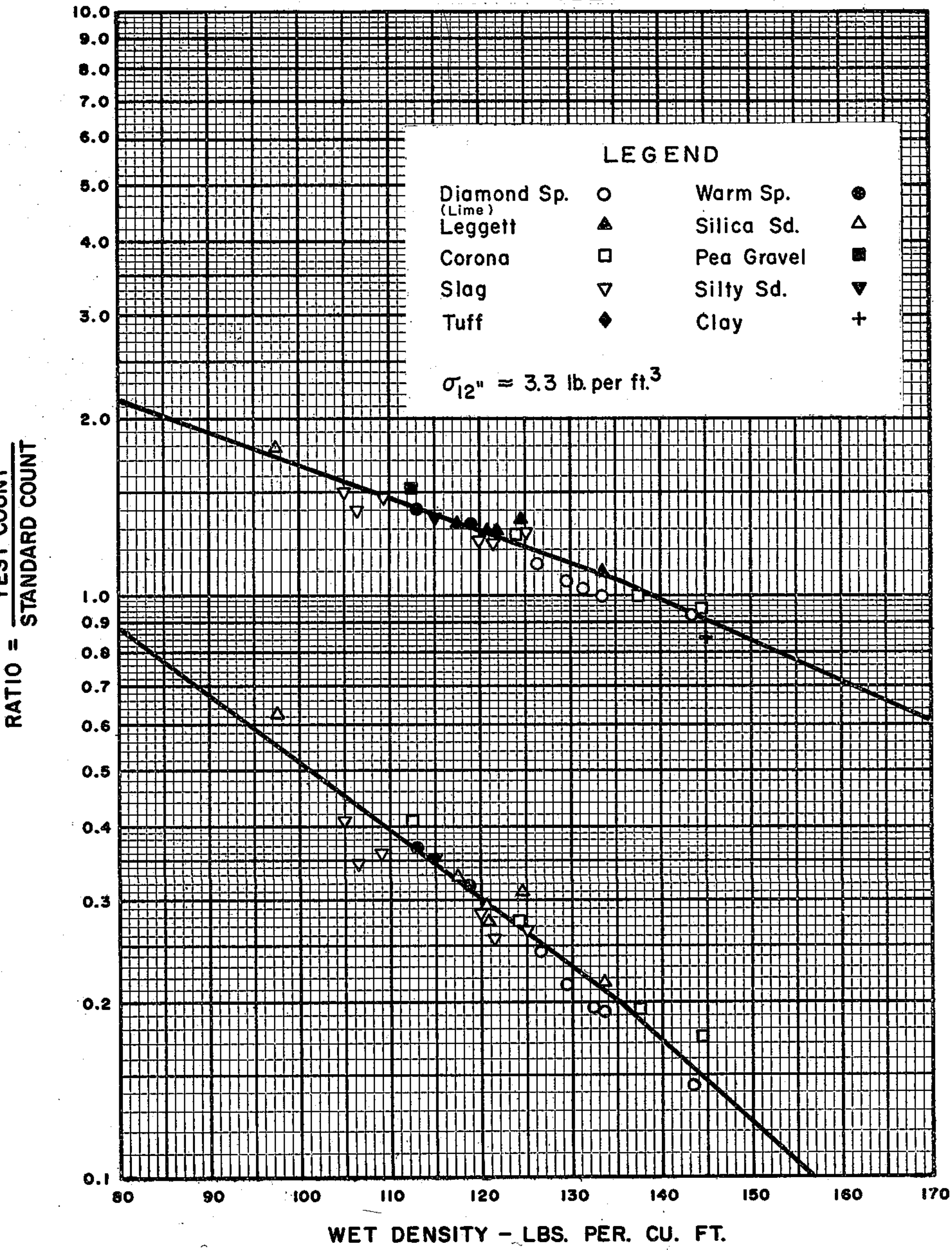

NUCLEAR CHICAGO
LEGEND
Diamond Sp. (Lime)
Leggett
Corona
Slag
Tuff
Warm Sp.
Silica Sd.
Pea Gravel
Silty Sd.
Clay
S-2-B
$\sigma_{12"} = 3.3$ lb. per ft.^{3}
RATIO = TEST COUNT / STANDARD COUNT
WET DENSITY – LBS. PER. CU. FT.
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
80
90
100
110
120
130
140
150
160
170

Figure 5

PORTAPROBE



The objectives of the project for which these samples were compacted were such that they were prepared in a routine or production testing basis. They were torn down shortly after their fabrication, and it was not possible to investigate any of the cases where an unusual variance occurred to see if the cause was determinable or correctable. At first glance there appears to be a considerable scatter to the data. However, the standard deviation (σ) of the data about the calibration line is approximately 3 lb per cu ft for the 10 in. transmission depth with the Nuclear Chicago gage, and 3.5 lb per cu ft for the Portaprobe at the 12 in. depth.

The variance of the data may be assumed to be equally divided between: [1] the random error in the nuclear test method itself; and [2] the difference between the calculated bulk density of the sample and the actual density being measured by the gage. Therefore, the standard deviation of the nuclear test method in determining the true probable density of a site may be estimated by the expression:

$$\sigma_n = \sqrt{\frac{\sigma}{2}} = 2.0 \text{ to } 2.5 \text{ lb per cu ft}$$

where (σ) is defined as the standard deviation of the bulk mold density data about the calibration line, and (σn) the standard deviation of the nuclear test.

The assumption that factor No. [2] does significantly contribute to the variance between bulk mold densities and nuclear readings on a compacted sample is supported by research conducted by the department in 1962 (15, Fig. 4). It was shown that there can be a difference of 2 to 6 lb per cu ft between the top and bottom halves of a large mold containing compacted soil, or 1 to 3 lbs from the average or bulk density of the sample. At different locations within the mold, the sand volume test indicated a difference of up to 5 lb per cu ft from the bulk density of the whole sample, (15, Fig. 3).

In later research conducted by the Materials and Research Department, the densities at various locations within similar large compacted soil samples were estimated by various means such as chunk densities, sand volume, and tube samples. The densities of the various layers placed in compacting the soil were also calculated on the basis of the weight and compacted volume of each layer. The range between minimum and maximum densities computed by the different methods for the individual samples ran from 1 to 7 lb per cu ft for twelve cases reported, (4, p. 146).

In any event, the indicated accuracy (2.0 to 2.5 lb per cu ft) of the gage-calibration system is considered adequate for construction control of soil compaction. This is especially true where a statistical sampling procedure is used (16), such as in our current Test Method No. Calif. 231. This research demonstrated that a single calibration curve determined on the master standards, (using gages meeting current California specifications) will be satisfactory for the common soils used in California highway construction. Some adjustment of the calibration curve may prove to be desirable for extreme soil types such as slag, lime soils, and possibly some granular soils. The subject is under study at the present time, and a final conclusion has not been reached.

The replicas of the prototype standards, which are to be used by the districts as references to the central set of master standards, have been fabricated. These are being tested at the present time, and it is anticipated that each of the districts will be provided a high and low density set shortly. A "calibration" density for the various test modes will be supplied with each standard, which may vary somewhat from the average or bulk density. Ordinarily, the nuclear gages will be initially calibrated on the master references. After this initial calibration, the district reference blocks will be used for interim calibration and checking of the instruments. The master standards will be rotated through the districts periodically for calibration of gages and correlation with the District reference standards.

LIST OF REFERENCES

1. Weber, William G., Smith, Travis, "Laboratory and Field Evaluation of Nuclear Surface Gages for Determining Soil Moisture and Density," Nuclear Measurements, H. R. Record No. 66, Washington, D. C., 1965.

2. Worona, V., Gunderman, W., "Field Evaluation of Nuclear Gages Used in Compaction Control of Embankments," Nuclear Measurements, H. R. Record No. 66, Washington, D. C.

3. Ralston, H. H., Anday, M. C., "Nuclear Measurement of Soil Properties," Nuclear Measurements, H. R. Record No. 66, Washington, D. C., 1965.

4. Smith, R. E., Weber, W. G., Smith, Travis, "A Basic Study of the Nuclear Determination of Moisture and Density," M & R - 225928, Calif. Dept. Pub. Wks., Div. Hwys., Sacramento, Nov. 1965.

5. Kühn, S. H., "Effects of Type of Material on Nuclear Density Measurements." Nuclear Measurements, H. R. Record No. 66, Washington, D. C., 1965.

6. Preiss, K., "Analysis and Improved Design of Gamma Ray Backscattering Density Gages," Nuclear Applications, H. R. Record No. 107, Washington, D. C., 1966.

7. Smith, R. E., Weber, W. G., Smith, Travis, "Field Evaluation of the Lane-Wells Road Logger," M & R 226208-1, Calif. Dept. Pub. Wks., Div. Hwys., Sacramento, June, 1965.

8. Ballard, L. F., Gardner, R. P., "Density and Moisture Content Measurements by Nuclear Methods," National Cooperative Highway Research Program Report #14, NAS-NRC Publication 1213, 1965.

9. Williamson, T. G., Witczak, M. W., "Factors Influencing the Application of Nuclear Techniques to Soil Compaction Control," H. R. Record No. 177, Washington, D. C. 1967.

10. Todor, P. C., Gartner, W., Jr., "Evaluation of Direct Transmission-Type Nuclear Density Gage for Measuring In-Place Density of Soils," Nuclear Applications, H. R. Record No. 107, Washington, D. C., 1966.

11. Anday, M. C., Hughes, C. S., "Compaction Control of Base Course Materials by Use of Nuclear Devices and a Control Strip Technique," H. R. Record No. 177, Washington, D. C., 1967.

12. Smith, R. E., Weber, W. G., Smith, Travis, "A Field Evaluation of Compaction Control with Nuclear Gages," M & R - 632637-6, Calif. Dept. Pub. Wks., Div. Hwys., Sacramento, August, 1968.

LIST OF REFERENCES (contd)

13. LeFevre, E. W., Manke, P. G., "A Tentative Calibration Procedure for Nuclear Depth Moisture/Density Gages," H. R. Record No. 248, Washington, D. C., 1968.

14. State of California, Department of Public Works, Division of Highways, Materials and Research Dept., "Specifications for Nuclear Density-Moisture Gage," revised Mar. 1, 1968.

15. Weber, W. G., Smith, Travis, "Laboratory Studies of Nuclear Surface Moisture and Density Gages," Calif. Dept. Pub. Wks., Div. Hwys., Sacramento, October, 1962.

16. Weber, W. G., Smith, Travis, "Practical Applications of the Area Concept to Compaction Control Using Nuclear Gages," Calif. Dept. Pub. Wks., Div. Hwys., Sacramento, January, 1967.

HIGHWAY RESEARCH REPORT

SLOTTED CORRUGATED METAL PIPE DRAINS

71-04

STATE OF CALI

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636453

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration August 1971

August 1971
Final Report
636453

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

SLOTTED CORRUGATED METAL PIPE DRAINS

Principal Investigator
Eric F. Nordlin

Co-Principal Investigator
J. R. Stoker

Assisted By
B. G. Page

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

ABSTRACT

REFERENCE: Nordlin, E. F., Stoker, J. R., and Page, B. G., "Slotted Corrugated Metal Pipe Drains", State of California, Department of Public Works, Division of Highways, Materials and Research Department Research Report 636453, August 1971.

ABSTRACT: The application of a slotted pipe drain in some areas subject to occasional wheel loads is beneficial to effective drainage design. The ability of the slotted pipe to carry legal wheel loads is investigated in this project. Also, the development and performance of slotted corrugated metal pipe drains as used on California highways are discussed. Both 14 gage and 16 gage corrugated metal pipe, 18 inches in diameter, were investigated. Based upon pipe deflection data under heavy wheel loads, the slotted drain pipe fabricated to standards specified in California Standard Plans, January 1971, is capable of carrying occasional legal highway wheel loads. However, a series of fatigue endurance tests should be performed on slotted pipe drains if frequent repetitive loads are anticipated.

KEY WORDS: Corrugated metal pipe, drains, pipes, drainage, inlets, wheel loading, deflection test.

ACKNOWLEDGEMENTS

The researchers are appreciative of the assistance and cooperation of district personnel on this project, particularly Mr. Tarbell Martin, Design, Mr. Hank Kreft, Construction, and Mr. T. D. Wells, Maintenance Superintendent, District 11, and Mr. Harvey Hopkins, Construction, District 07.

A special thanks goes to Mr. C. M. Simpson of the Materials and Research Department for his efforts in compiling and presenting the data for this project.

Slotted drain pipe incorporating special alternate designs for this project were furnished by the Metal Products Division of Armco Steel Corporation. Their cooperation in this effort is also gratefully acknowledged.

This work was accomplished with the cooperation of the U. S. Department of Transportation, Federal Highway Administration, as Item D-4-79 of the HPR program. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

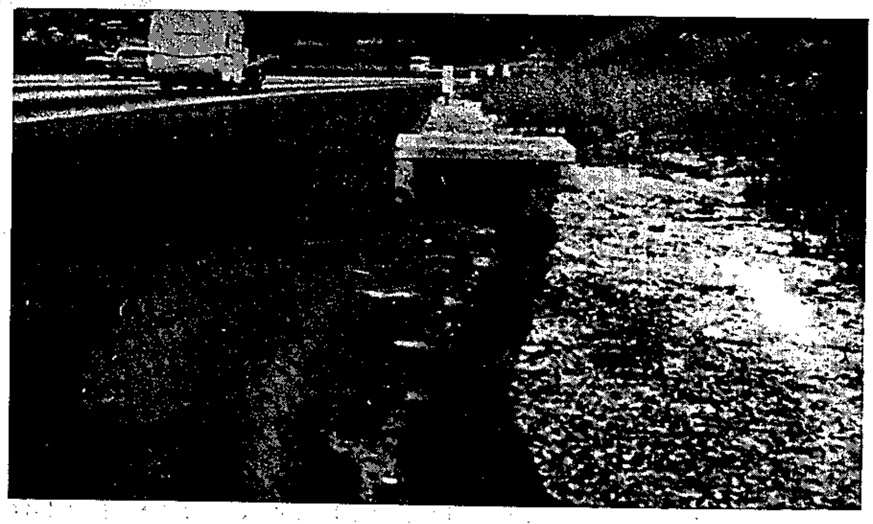
TABLE OF CONTENTS

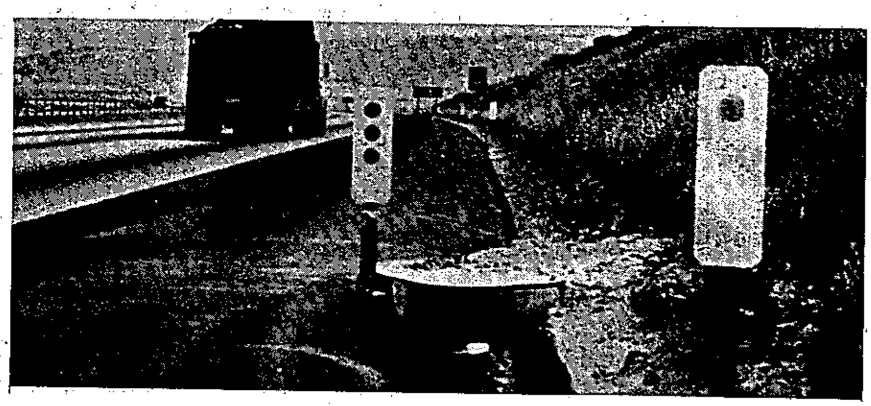
INTRODUCTION

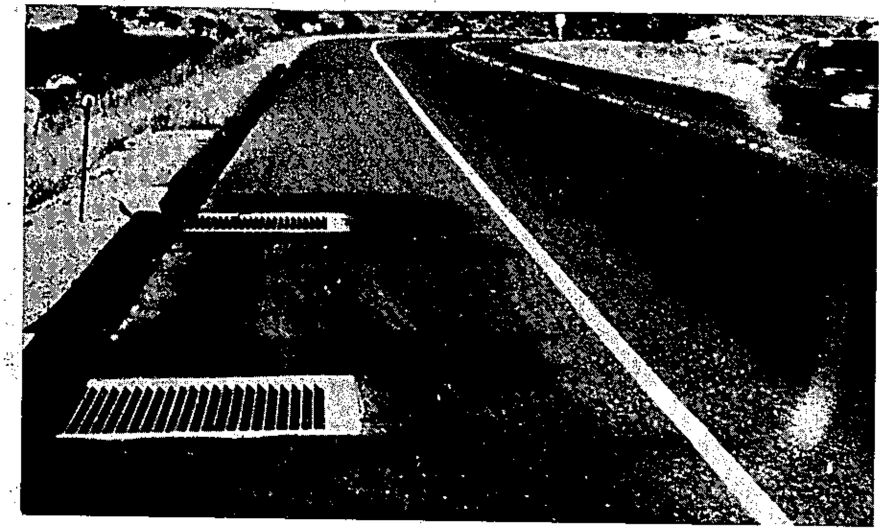
The early collection and dissipation of all surface water on the traveled roadway is a requirement that faces all designers and hydraulic engineers. One method of intercepting surface water without the need for any form of a surface projecting inlet structure is the slotted corrugated metal pipe drain. This drain consists of 12, 18 or 24 inch diameter corrugated metal pipe with a continuous 1-5/8 inch wide longitudinal drain slot. Continuity of the pipe is provided by design as shown on Standard Plan Drawing D98-4, Drawing No. 1 in the Appendix.

Early installations of the slotted drain pipe were in the median where the median barriers generally precluded any wheel load applications and, therefore, after the paving operation few, if any, vehicle traffic induced stresses were applied to the pipe. The hydraulic potential of this type drain is such that placement in shoulder or ramp areas is often desirable where cost is not excessive. Since trucks occasionally park or stop in the shoulder areas, it is necessary to accommodate occasional heavy wheel loads in the slotted drain pipe design for such locations. Some examples of designs that may be replaced by slotted pipe drains are shown in Figure 1.

This research project was initiated to review the development and performance of slotted CMP drains and to perform full scale load tests to determine the feasibility of using these drains in occasional traffic bearing areas.







EXISTING DRAINAGE INLETS

Slotted drain pipe would improve the system.

FIGURE 1

CONCLUSIONS

1. The current slotted drain pipe design is capable of withstanding occasional wheel loads with the longitudinal grate bar flush with the A.C. surface as shown in Drawing No. 3 in the Appendix. Therefore, the additional strength obtained from the alternate designs installed as part of this project could not be determined.

2. The slotted drain pipe intercepts surface sheet flow thereby precluding a ponding effect which tends to reduce clogging by runoff carried debris, especially redwood bark.

3. Backfill conditions or compactive effort influence the pipe deflections.

4. In areas that appear to be well compacted, the 16 gage pipe resists loads as well as the 14 gage pipe.

5. A modification to the angle slot type design was found necessary to prevent pipe closure at the slot.

6. The slotted drain pipe designs that are shown in the California Standard Plans dated January 1971 (D98-4) and the revised SD98-5 dated April 21, 1971 (see Drawing Nos. 1 and 2 in the Appendix) should not be used in areas subject to motorcycle or bicycle traffic. In such locations the details shown in Drawing No. 3 in the Appendix would be preferable.

RECOMMENDATIONS

1. When slotted drains are used in an area subject to two wheel vehicular traffic (motorcycles and bicycles), the use of the grate slot type with bar spacers at top and bottom installed flush with the surface is recommended. This type is also considered easier to maintain. See Drawing No. 3 in Appendix.

2. Compaction effort around slotted drain pipe should be given special attention in vehicle traffic bearing areas.

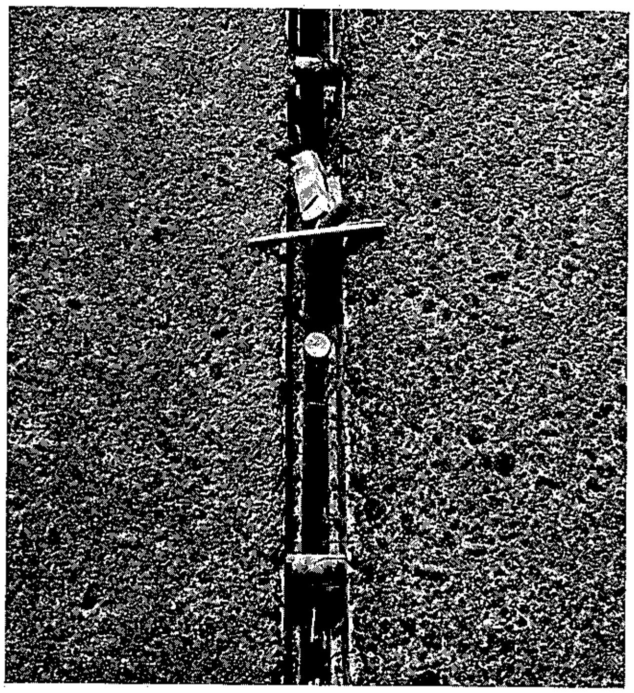
3. It is recommended that slotted drain pipe be considered whenever the "sheet flow" interception of surface water will facilitate and promote traffic safety and where such an installation is economically feasible.

4. If numerous repetitive vehicle wheel loads are proposed for slotted drain pipe installations, further investigation on the fatigue life of the welded or bolted connections, and possibly the pipe itself, should be conducted.

DISCUSSION

This project consisted of two parts. The first part involved the observation of in-place installations and the discussion of existing designs, construction procedures and problems, hydraulic performance, and maintenance with involved personnel. The installations observed were 18 inch diameter corrugated metal pipe in median areas. Generally these drains would not be subjected to wheel loads.

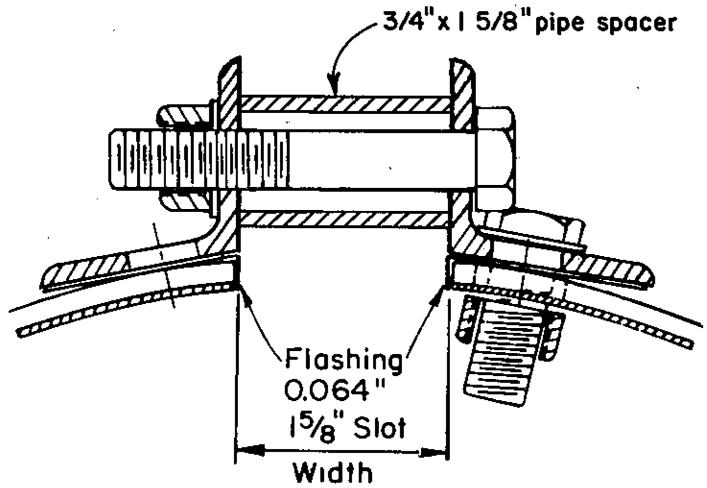
The most significant observations regarding design-fabrication-construction procedures were of an installation near Post Mile 13.5 on Route 60 in Los Angeles. This angle slot type slotted drain (similar to that shown in Drawing No. 1 of the Appendix) sustained approximately 15,000 vehicle loadings during a land-slide repair detour operation. Few, if any, of these vehicles were trucks, however. Traffic related distress was not observed but an undesirable feature was found to exist at intermittent locations throughout the project. Slippage occurred between the angle and the flashing as shown in Figures 2 and 3. The slot width reduced to approximately 1 inch at several locations and



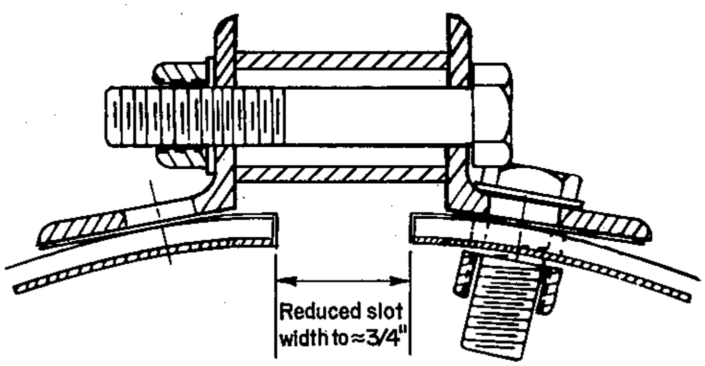
PIPE CLOSURE ON ANGLE SLOT TYPE SLOTTED DRAIN

FIGURE 2

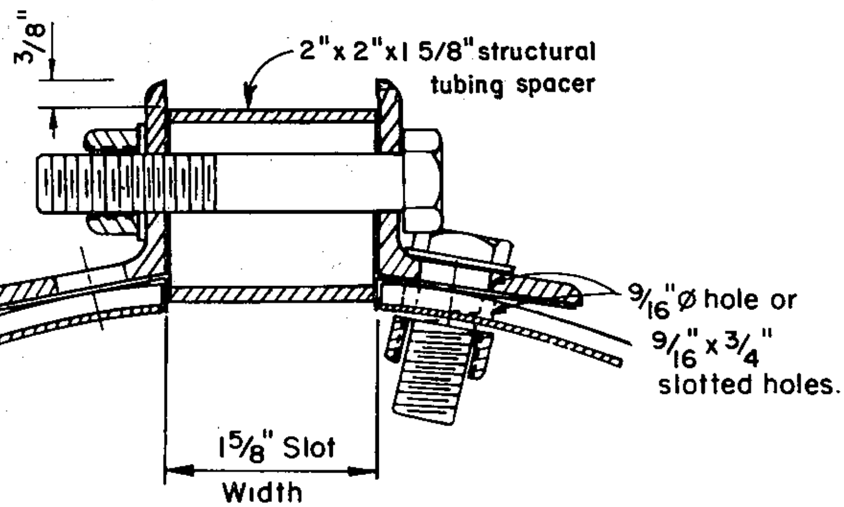
ANGLE SLOT DETAIL



INITIAL DESIGN



OBSERVED DISTORTION



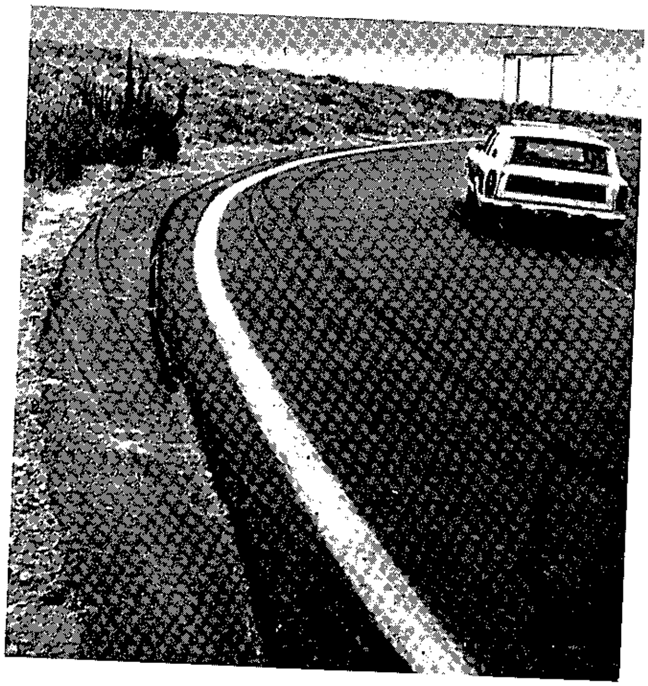
REVISED DESIGN

Figure 3

in some places a quarter could be rested on the resulting ledge. This narrow opening reduces efficiency and establishes an undesirable hydraulic loss at the inlet. Also, the resulting shelf catches rocks and debris which will eventually clog the drain if not maintained periodically. To prevent this pipe slot closure, a recent design revision relocates the structural tubing spacer 3/8 inch lower so that it will restrain the pipe and flashing. This revised detail is shown in Figure 3 and in Drawing No. 2 of the Appendix (SD98-5 dated April 21, 1971).

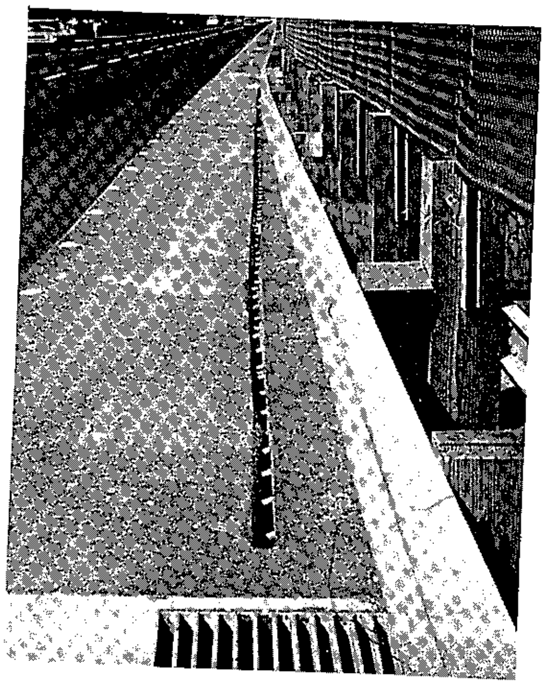
A very practical slotted drain pipe installation that intercepts runoff to an interchange ramp is shown in Figure 4. The AC surfacing adjacent to the drain inlet was observed to have several tire marks indicating that vehicles had crossed without any apparent distress to the pipe or the surfacing. It appears that most of these marks were made by passenger vehicles.

Figure 5 partially exhibits the twisting that occurred with an installation of slotted drain pipe utilizing the earlier flange slot type design. This design has been deleted from the Standard Plans because of the construction problems in maintaining alignment and for reasons of economy.



DRAIN INSTALLATION ON AN INTERCHANGE RAMP

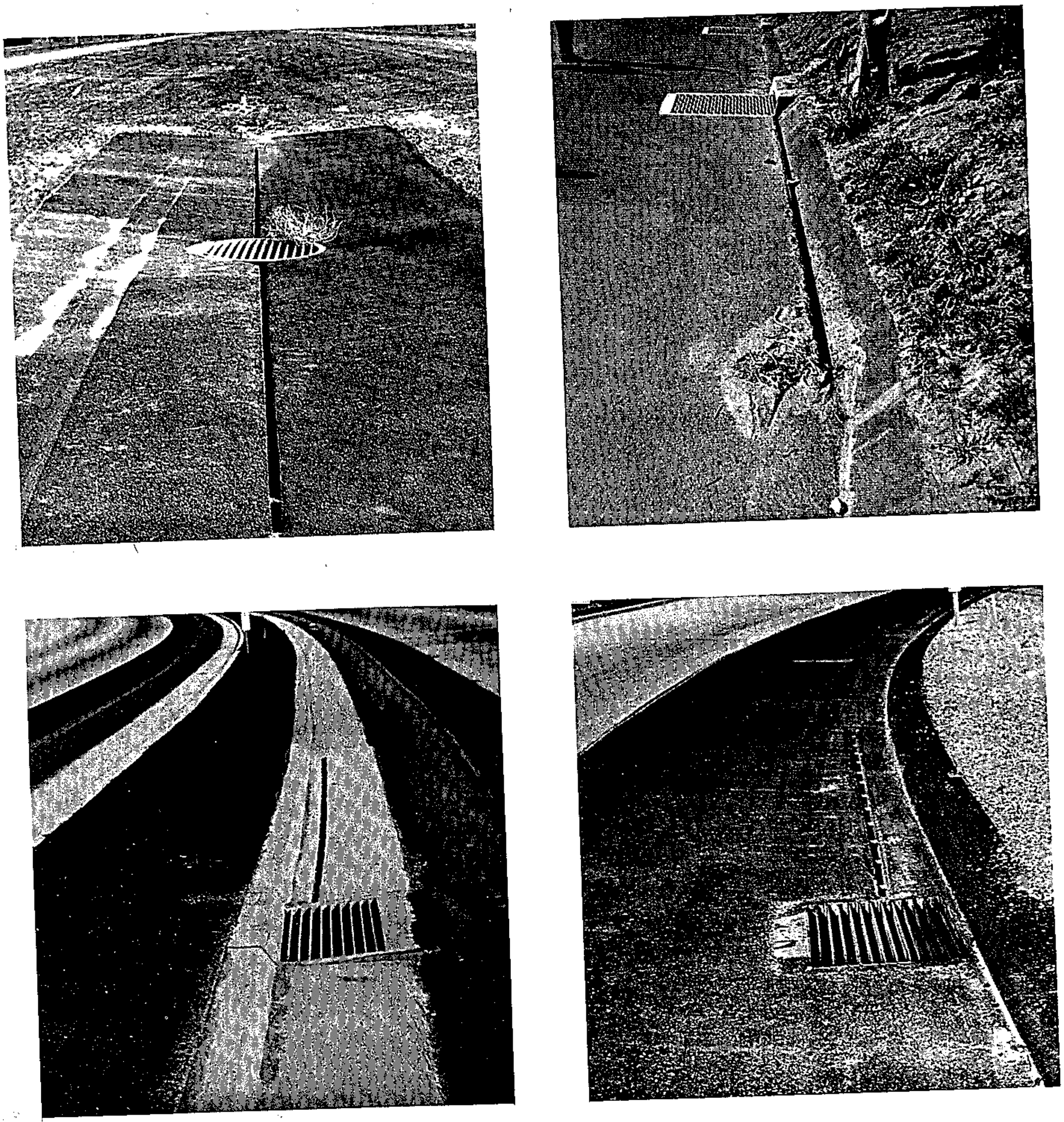
FIGURE 4



FLANGE SLOT TYPE SLOTTED DRAIN DESIGN

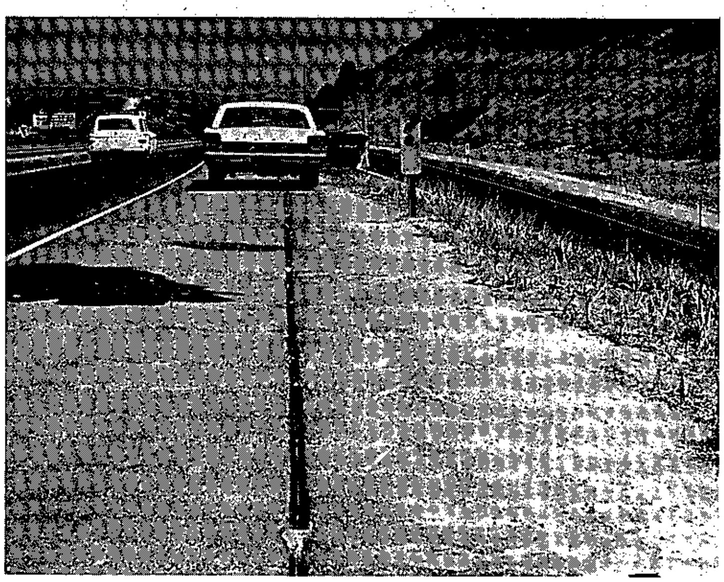
FIGURE 5

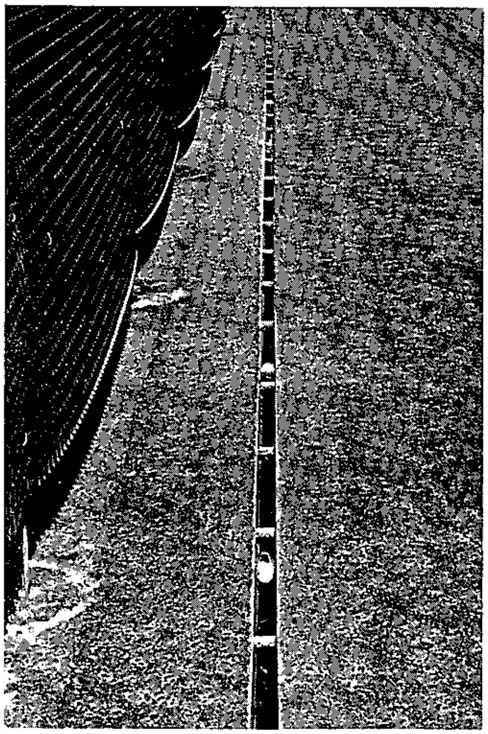
Several other applications of the slotted drain pipe that have been observed recently are presented in Figures 6 and 7.

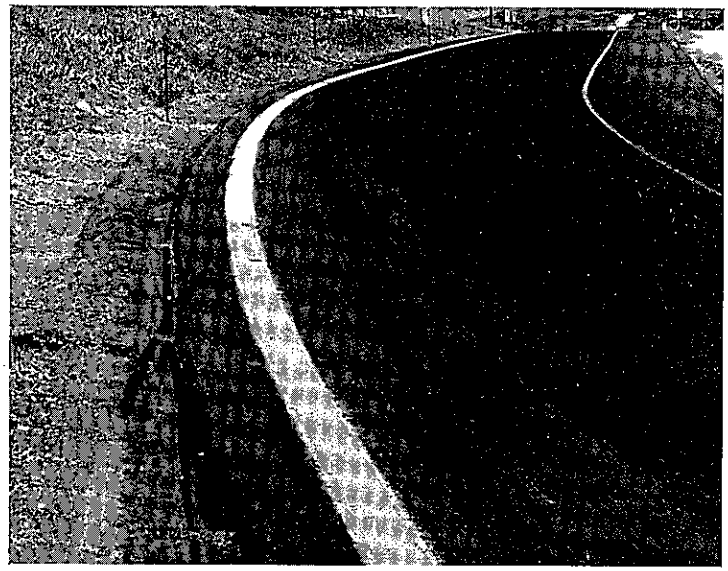


SLOTTED DRAINS SUPPLEMENTING OTHER DRAINAGE INLETS

FIGURE 6







SLOTTED DRAIN WITHOUT DIKES OR CURBS

FIGURE 7

In discussing the merits and shortcomings of the slotted drain pipe with district personnel, it was reported that redwood bark has not clogged the slotted drains in areas where this might have been a problem. It appears that the slotted pipe intercepts the water in such a manner that the bark is not easily transported to the slot. This "sheet flow" interception would also tend to preclude ponding in the collection of storm runoff.

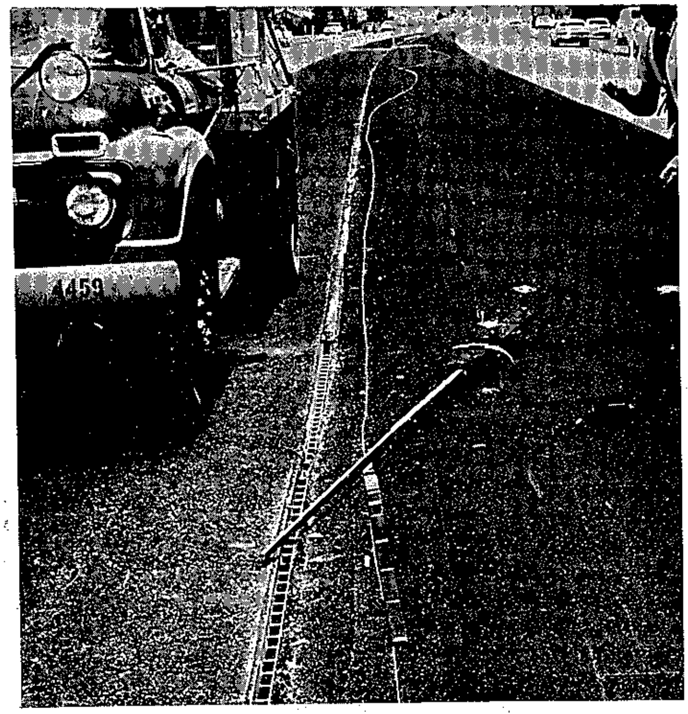
To assist maintenance personnel in cleaning slotted drain pipe grates, consideration has been given to placing the grates flush with the surface rather than 3/4" below the pavement surface as shown in Drawings No. 1 and 2 in the Appendix. Also, this placement would facilitate motorcycle and bicycle traffic. Therefore the drain pipe was installed on a construction project on Route 11-SD-805-3.5/7.3 with the longitudinal bar flush with the AC surface. An alternate design incorporated in the above project provided a second row of cross bar spacers at the surface to accomplish the objectives of this relocation (see Drawing No. 3 in the Appendix).

The second part of this research project involved evaluating the load carrying ability of the most promising designs by comparing the deflection characteristics of the pipe under wheel loads. The first investigation was made using a Benkelman Beam to measure the deflection of an 18" diameter standard grate type slotted drain pipe under a 12.3 kip single axle load as shown in Figure 8. This installation was in the median of a project on Route 07-Ora-55-4.6/17.8. The trench was excavated to grade with a shaped bucket and a sand-cement grout was used for backfill material. This is a typical installation practice when several lengths of slotted pipe are placed.

Deflections were measured at several distances from the slot to determine the critical load location for pipe deflection. As expected, the maximum deflections were measured with the wheel load at or near the pipe slot. The maximum pipe deflection was 0.093 inch.

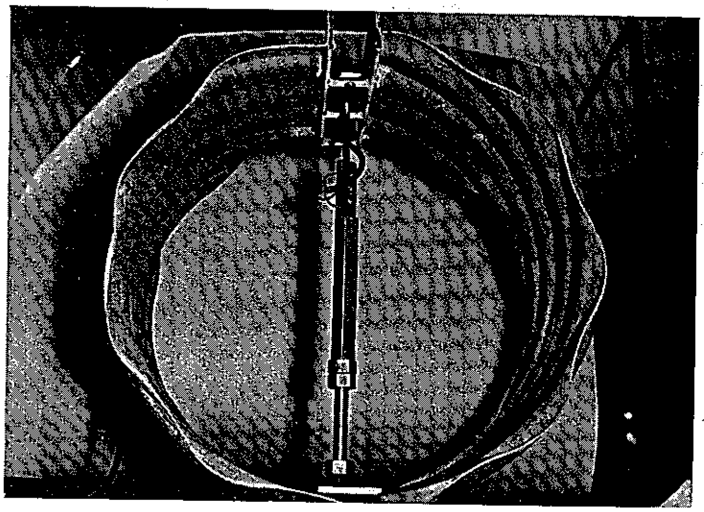
Considerable difficulty was encountered in positioning the beam-wheel load combination in the vicinity of the slot. Therefore, to perform the remaining investigations, deflection measuring equipment was designed to fit inside the slotted drain pipe. This eliminated the chance of probe damage by the truck tires and, also, provided a greater confidence in the deflection reading by reducing the chance of the probe slipping during the loading. The testing apparatus is shown in Figure 9.

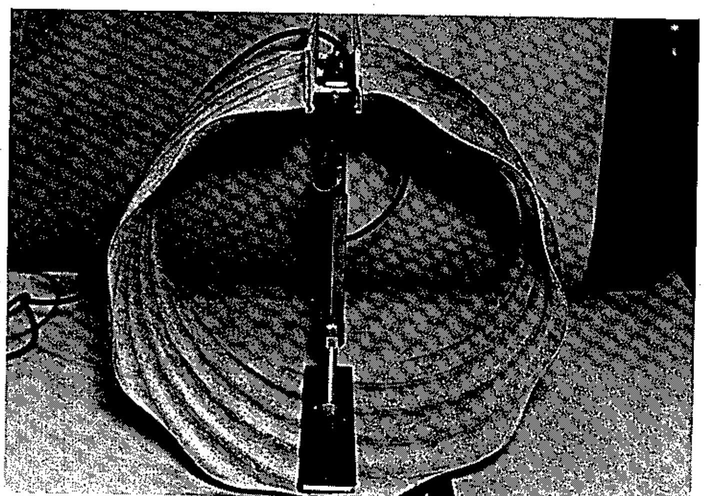
This internal measuring device consists of a linear potentiometer capable of accommodating movements to 1.3 inches. The potentiometer was calibrated with a transducer/strain indicator to provide vertical movements in mils (one thousandth of an inch). The potentiometer was supported from the base by an adjustable leg that accommodated variations in pipe shape or diameter. An initial reference for each set of readings was obtained by an



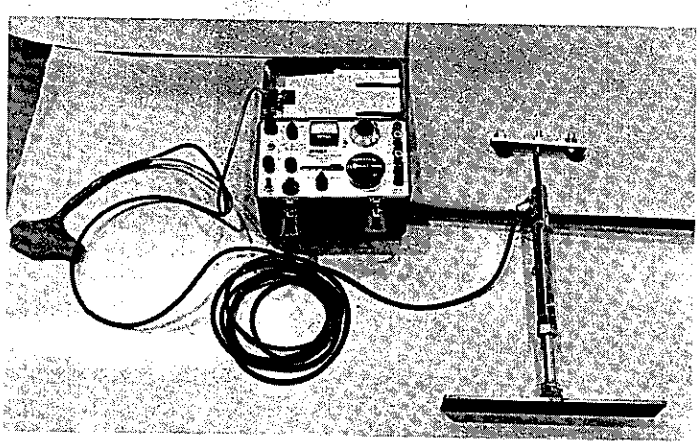
DEFLECTION MEASUREMENTS ON 07-ORA-55
WITH THE BENKELMAN BEAM

FIGURE 8





INTERNAL
INSTRUMENTATION
IN PLACE

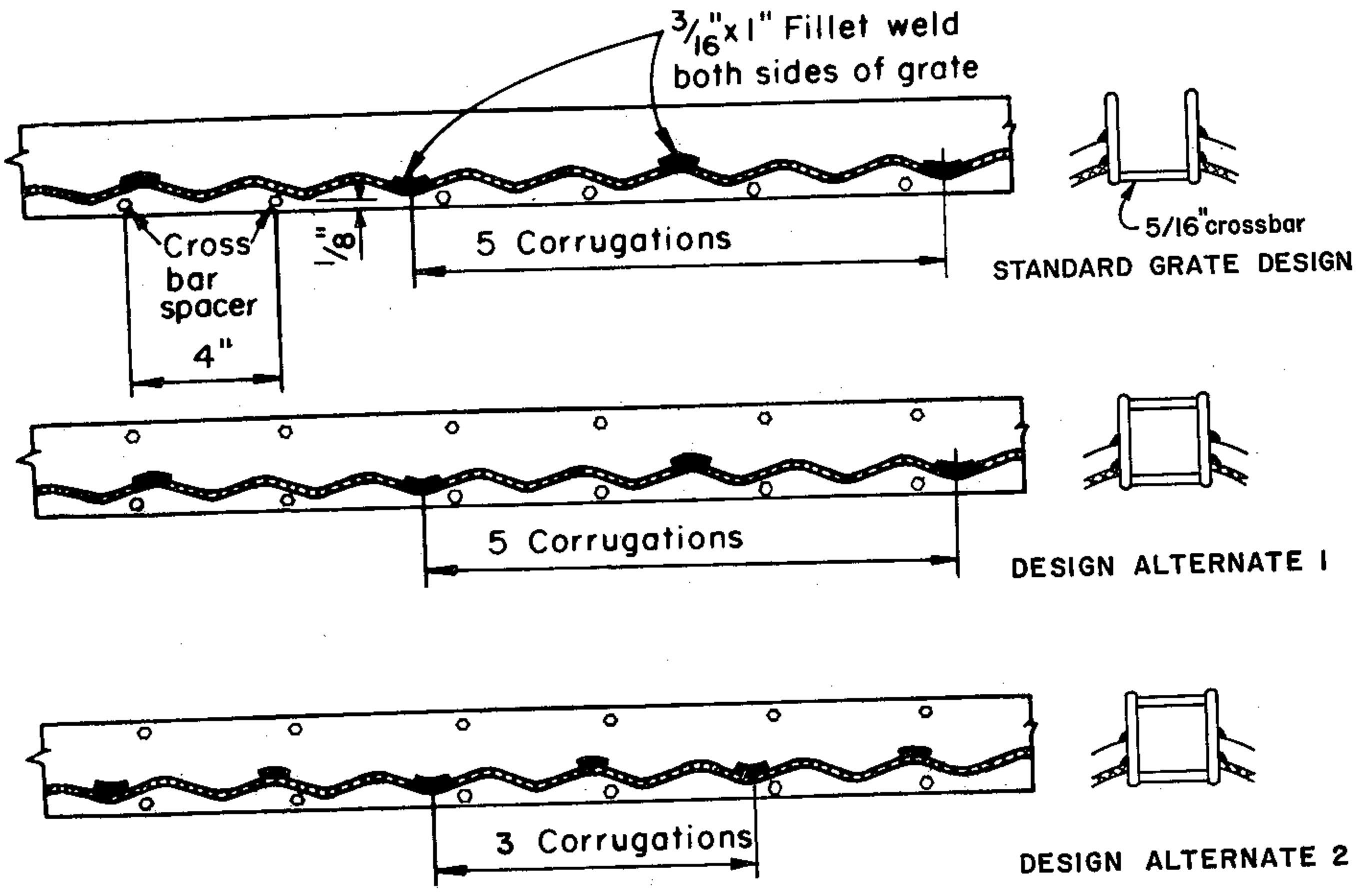


EQUIPMENT INCLUDING
TRANSDUCER/STRAIN
INDICATOR

FIGURE 9

adjustable set screw in the grate clamp assembly. Movements between the grate or pavement surface and the pipe invert were measured.

The second and primary investigation was conducted on a going construction project on Route 11-SD-805-3.5/7.3. Three designs of grate slot pipe were installed at three locations on this project in both 14 gage and 16 gage corrugated metal pipe, 18 inches in diameter. These three grate slot designs are shown in Figure 10. At one of these locations a length of 14 gage 18" diameter unslotted standard CMP was also installed for comparison.

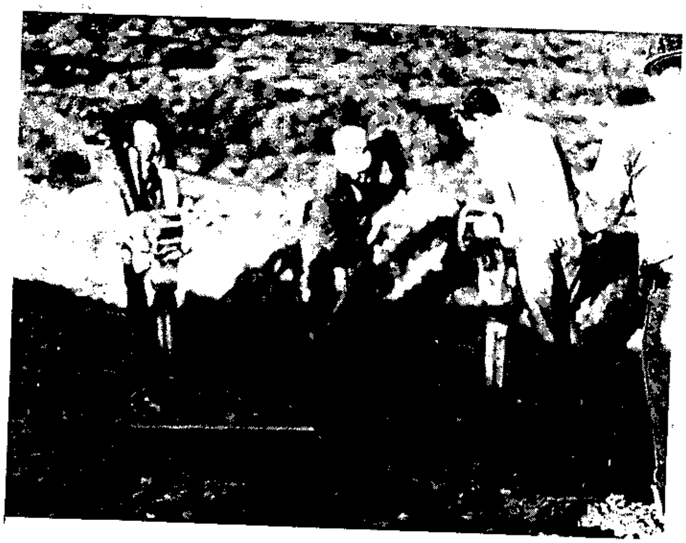


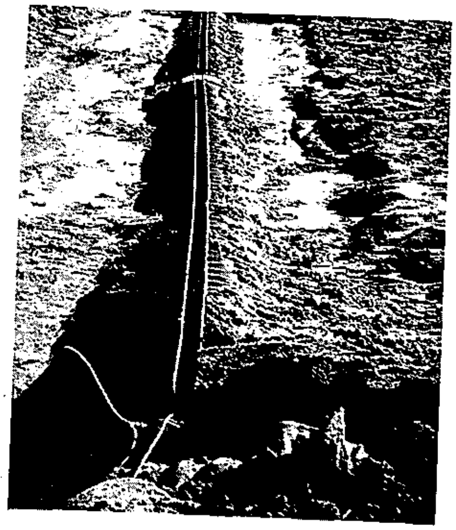
GRATE SLOT DETAIL

FIGURE 10

An exact evaluation of the structural requirements of the drain was not determined; however, an analytical evaluation of the standard grate slot design indicated that the probable failure mode of the grate slot would be the single row of 5/16 inch cross bar spaces in bending. The second most probable failure mode was determined to be the fillet welds in shear. Therefore, Design Alternate 1 consisted of modifying the standard grate design by adding a second row of cross bar spacers at the top of the longitudinal bar. Design Alternate 1 was further modified resulting in Design Alternate 2 by increasing the number of fillet welds to 5/3 the original number. The alternate designs were expected to accommodate legal wheel loads if the current standard design could not.

Material from the trench excavation was used as pipe backfill on the 11-SD-805-3.5/7.3 project. This material was a sandy embankment soil combined with some Class 4 aggregate subbase and Class 2 aggregate base. Location #1 utilizing Design Alternate 1 was an exception to this as the structural section consisted of 0.50' CTB over the aggregate subbase in the shoulder. The backfill material around the drain pipe was compacted with two Master T-1000 portable compactors as shown in Figure 11. These installations were made with normal construction procedures, inspection, and controls.



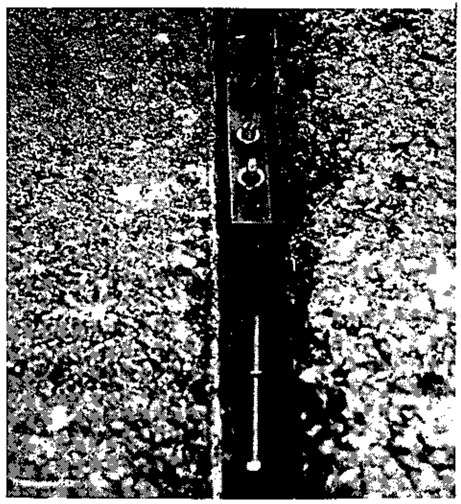


BACKFILL COMPACTION ON SLOTTED DRAIN PIPE FOR 11-SD-805-3.5/7.3

FIGURE 11

The asphalt concrete in the shoulder areas at all three locations on Route 11-SD-805-3.5/7.3 had a 0.25' design thickness and was placed about one week prior to the deflection measurements which were made with the internal pipe deflection measuring instruments as shown in Figure 12.

DEFLECTION MEASUREMENTS ON 11-SD-805 WITH INTERNAL INSTRUMENTATION



DEFLECTION APPARATUS IN PLACE

FIGURE 12

The third investigation was made on a construction project on Route 11-SD-805-17.1. This installation utilized a shaped trench and an asphaltic concrete backfill and surfacing material. A picture of the excavation bucket used to shape the trench is shown in Figure 13. This project was not open to traffic at the time of this investigation, but the asphalt concrete surfacing had been placed for several weeks.

FIGURE 13

Deflection of the drain pipe under a wheel load was utilized to evaluate the performance and capability of the tested slot designs and pipe gages to carry applied wheel loads. A distinction should be made between the results measured with the linear potentiometer-strainsert (internal) instrumentation that used the pipe invert for a reference and the results of the Benkelman Beam that uses an adjacent surface area as reference. Because the pipe invert probably deflects under load, it was expected that the Benkelman Beam deflection readings would be slightly higher for a given pipe-wheel load situation. This apparent discrepancy was reduced somewhat because the internal measurements were made with a static load whereas the Benkelman Beam readings are taken with a transient or slow moving load. Deflections under a moving load are generally less than under a longer held static load. Based upon a very few deflection observations on the standard CMP installation, the internal measurements are approximately 70 percent of the Benkelman Beam measurements. However, a valid, reliable comparison cannot be made because of the few deflection values.

The internal pipe deflection measuring device was considered more desirable for this application because it was (1) easier to position, (2) much easier to repeat a reading, (3) not subject to surface slipping, (4) less susceptible to varying surface irregularities, and (5) not subject to damage by the truck tire.

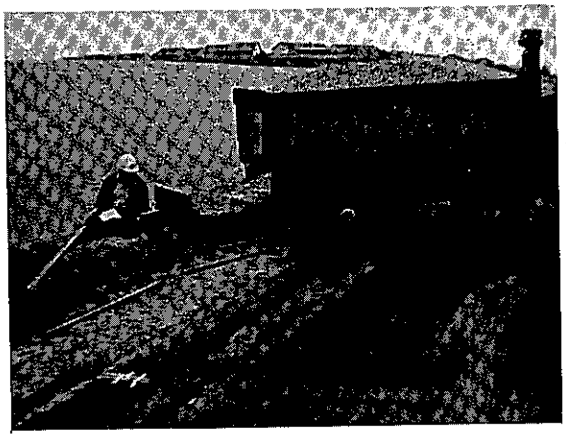
Internal deflection measurements were made on all of the slotted drain pipe installations investigated except for the initial measurements on the project on Route 07-Ora-55. The Benkelman Beam was used for measuring deflections of slotted drain pipe under a 12.3 Kip single axle load on project 07-Ora-55 and also for determining the deflections of shoulders and the deflection of standard corrugated metal pipe on the projects on Route 11-SD-805. Deflection measurements were taken on the Route 11-SD-805 projects with the center of the dual straddled over the slot. These positions are shown pictorially in Figures 14a and 14b.

LOAD ORIENTATIONS AS APPLIED TO THE SLOTTED DRAIN PIPE

(a) Load 10" from center line. (b) Load on center line.

FIGURE 14

Additional tests were made on the Route 11-SD-805 projects at Locations 2 and 3 between P.M. 3.5/7.3 and at Location 4 at P.M. 17.1 with the wheel perpendicular to the slot as shown in Figure 15. This orientation placed all of the applied load directly on the pipe, and therefore resulted in greater pipe deflections. It was assumed that trucks using a flotation* tire would apply a direct load to the pipe in a similar manner.



LOAD PERPENDICULAR TO SLOT

FIGURE 15

On the Route 11-SD-805 projects, 14 Kip, 16 Kip, and 21 Kip single axle loads were applied to the slotted pipe, shoulder areas, and a length of corrugated metal pipe extending from the slotted pipe. The resultant measurements are tabulated in Table 1. The negative readings shown in this table indicate that the position of the load and the soil conditions were such that the lateral pressures influenced the pipe distortion more than the vertical pressures. This resulted in a small upward movement of the pipe slot.

The existing cross slope of the pavement shoulder at Location 2 on Route 11-SD-805 was approximately 6% greater than at the other locations, and, therefore, the applied wheel loads are larger here than at the other locations since the lower side wheels were used in the tests. Theoretically (considering this larger slope) the dual wheels used in the test carried 56% of the total axle load. Therefore, the measured deflections shown on Figure 16 are plotted against adjusted axle loads of 15.6 Kip (14 x 0.56 x 2) to provide relative comparisons with other loads at 14 Kip.

While loading the slotted drain installation to obtain deflection values, considerable movement was observed at the upstream terminal end of the slotted pipe. This movement resulted because

* The flotation tire is a very wide tire that is sometimes considered an alternate to the standard dual tires.

the slot in the last six inches of the pipe was not supported by the grate, thus allowing some closure of the slot when the load was applied. A subsequent revision of the metal end cap provides circumferential support to the pipe end which will reduce the stress at the end connections. The revised design is shown in Drawing No. 2 of the Appendix.

The deflection data obtained by this investigation is considered to be typical for slotted drain pipe in shoulder installations. Variations in the measured values are expected to be rather large because of the segregation and variation in the backfill material, the applied compactive effort, the location of the applied load with respect to the measuring instrument, and to a lesser degree variations inherent in the testing equipment and operator skills.

Neither visual observations nor test data indicated any failure of grate components or welds during the testing.

ANALYSIS OF RESULTS

Relatively high deflection values were measured on Route 11-SD-805 at Location 2 between P.M. 3.5/7.3 and Location 4 at P.M. 17.1. When the data from Table 1 for Location 2 is compared to that for Locations 1 and 3, it appears that the soil is more resilient or that a lesser degree of compaction was attained at Location 2. This is shown by the measured pipe deflections and by the Benkelman Beam deflections in the shoulder. The comparatively high permanent set values indicate that a lower relative compaction existed at Location 2.

The comparatively high deflections measured at Location 4 at P.M. 17.1 are attributed to voids resulting from the physical dimensions of the shaped trench, the pipe diameter, and the AC backfill material. The creep rate under load was such that up to three minutes was necessary to obtain a stabilized deflection value. The comparative high deflections suggest that for traffic bearing areas, dense graded asphaltic concrete is not an effective pipe backfill material when used with the shaped trench.

Just as the flotation tire applies more stress to a flexible pavement[1], it will also induce greater stresses in the slot connection and pipe than the dual wheel load. In typical load orientations the dual wheel load applies more of a "balanced" load (lateral and vertical) on the pipe than the single flotation tire that is sometimes used as an alternate. As the pipe deflects under a dual wheel, more of the load will be carried by the portions of the dual wheel not over the pipe. Thus more lateral soil support will be provided to enable the pipe to withstand larger vertical wheel loads. Only a few trucks have been observed to use the flotation tire at this time, and the percentage to the total truck volume is assumed to be very small. Therefore, the typical maximum values imposed on the slotted drain are applied by the dual wheel load at the center line, parallel to the pipe. An occasional maximum value will be imposed by a flotation tire (represented by test data obtained with the dual perpendicular to the slot).

The deflection data in Table 1 indicates that the slotted pipe is capable of toleration deflections up to at least 0.380 inch. It appears that for a well compacted installation, legal loads applied by dual wheels would cause deflections less than 0.100 inch. Also, legal loads applied by flotation tires would cause deflections less than 0.200 inch.

Therefore, it is concluded that the existing slotted drain design is capable of supporting heavy wheel loads that may be occasionally applied in the highway shoulder or interchange ramp areas.

For the purpose of comparing variables, deflection data for the applied wheel loads as shown in Table 1 was proportioned to deflections for equivalent 14 Kip single axle loads. This proportioning is a direct ratio for the Benkelman Beam deflections measured in the shoulder. The average values are projected from zero in Figure 16 to show the relative shoulder deflection values at Locations 1, 2, and 3 on Route 11-SD-805-3.5/7.3. However, the internal measurement of pipe deflections requires additional considerations for proportioning. Since some "set" usually resulted from a previous load, this was considered when proportioning the pipe deflections. It is believed that pipe deflections will not be linear until a uniform lateral support is provided for the pipe and, therefore, only points are plotted.

The resultant averages are presented in Table 2 and Figure 16. The tabulated average set values in Table 2 are the difference between the average deflection and the average rebound for the listed loading position.

In addition to supporting the observations made from the individual measurements, the average values indicate that very little benefit can be realized from the 14 gage pipe <u>if</u> the bedding and backfill material is not resilient and is well compacted. This is exhibited in Figure 16 at Locations 1 and 3 where the average pipe deflections were very close for 14 and 16 gage pipe. However, unless special attention is applied to the compaction effort, the 14 gage drainage pipe is probably justified in traffic bearing areas.

Because the average deflections of the slotted drain pipe for dual wheel loads (the most prominent type on the highway) do not exceed the average deflections measured in the shoulder area, it appears that the existing designs are adequate in traffic bearing areas. However, if numerous wheel load applications are anticipated for the slotted drain pipe installations, an investigation to determine the traffic fatigue life of the slotted drain pipe and its connections should be conducted. The data measured during this investigation can be used to establish reasonable test limits for such an investigation.

TABLE 1

(Deflection, Mils)

Location	Pipe Gage	Run	Single Axle Load, Kip: Truck Parallel to Pipe, 10" from CL† 14	16	21	At CL† 14	16	21	Truck Perpendicular To Pipe 14	16	21	Permanent Set After Testing With All Loads
11-SD-805-3.5/7.3												
1.	14	1	3	8	10	18	18	31				
	16	1	15	12	15	16	36	47				
	Shoulder*		38	45	56							
2.	14	1	-14	9	8	19	62	90	119	130	101	16
		2	--	--	--	24	55	56	73	114	150	35
	16	1	-12	76	105	87	149	171	183	241	325	112
		2	--	--	--	55	52	101	161	159	237	14
	Standard CMP		--	--	--	95	90	125				
	Shoulder*		65	45	93							
3.	14	1	3	9	24	24	34	11	70	80	97	17
		2	3	-16	-9	28	38	65	104	108	170	9
	16	1	14	38	45	25	42	65	93	102	154	43
		2	24	9	23	30	25	45	90	81	121	2
	Shoulder*		29	33	42							
11-SD-805-17.1												
4.	14	1	17	57	97	63	94	137	182	171	282	57
		2	19	68	112	95	104	167	194	250	380	48
07-Ora-55												
5.	16	1								121**		0**
	Shoulder*		39-74 Avg.			=	56**					

* Measurements were taken several feet from the pipe.

** Values are adjusted to 16 Kip from the applied 12.3 Kip single axle load measured with the Benkelman Beam.

† Location of centerline of dual wheels.

TABLE 2

Average* Deflections, Mils

	Equivalent 14 Kip Single Axle Wheel Loads			
	Parallel Loading Average at CL Pipe		Perpendicular Loading Average at CL Pipe	
Location	Deflection	Set	Deflection	Set
11-SD-805-3.5/7.3				
1. 14 gage	18	0	--	--
16 gage	26	0	--	--
Shoulder	38			
2. 14 gage	23	7	77	3
16 gage	56	17	142	6
Shoulder	55			
3. 14 gage	24	6	76	3
16 gage	32	13	76	0
Shoulder	29			
11-SD-805-17.1				
4. 14 gage	97	28	208	64
07-Ora-55				
5. 16 gage	--	--	106**	--

* The 16 Kip and the 21 Kip single axle loads have been proportioned to equivalent 14 Kip axle loads.

** Measured with the Benkelman Beam for 12.3 Kip single axle loads.

LOAD - DEFLECTION RELATIONSHIPS

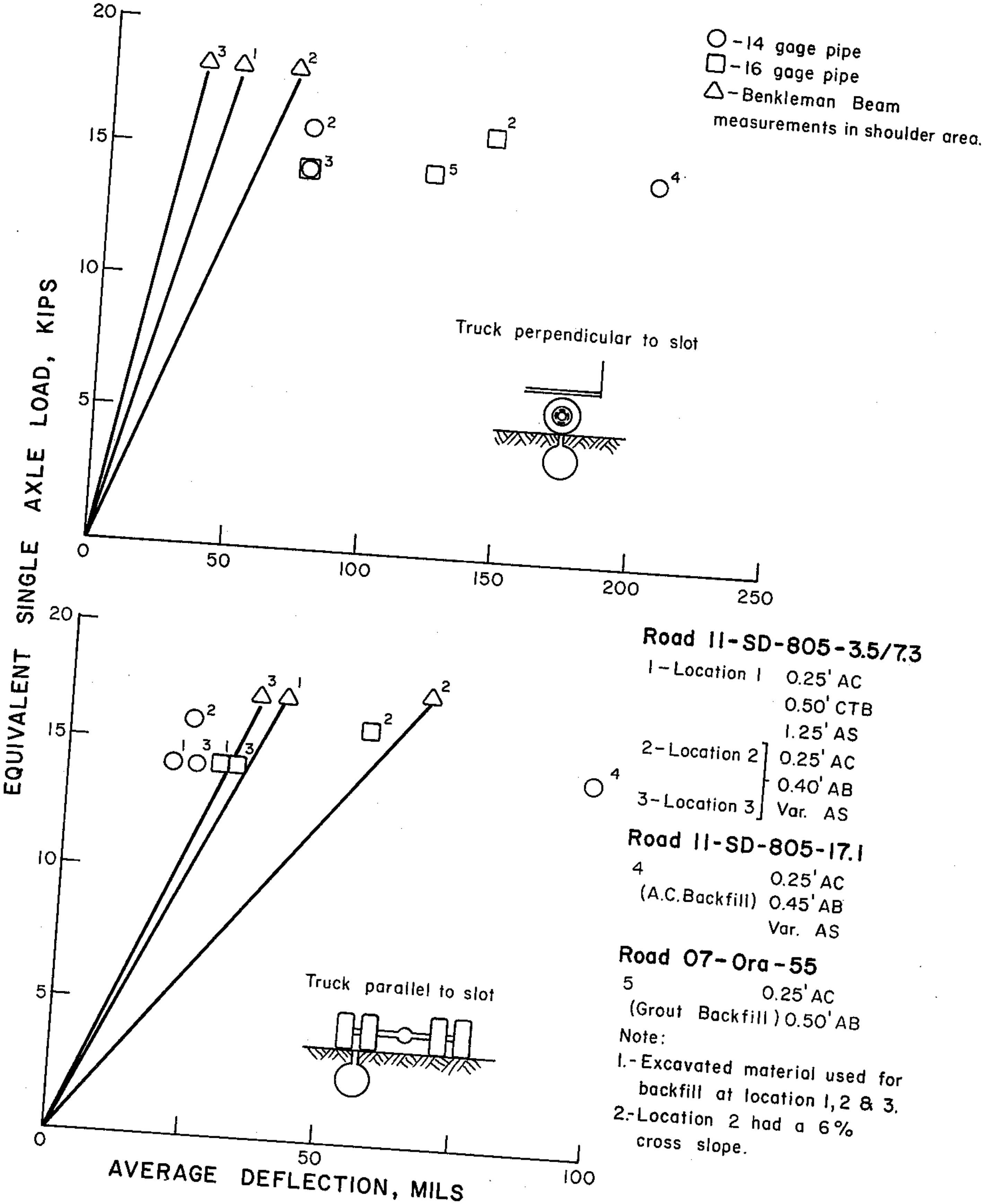


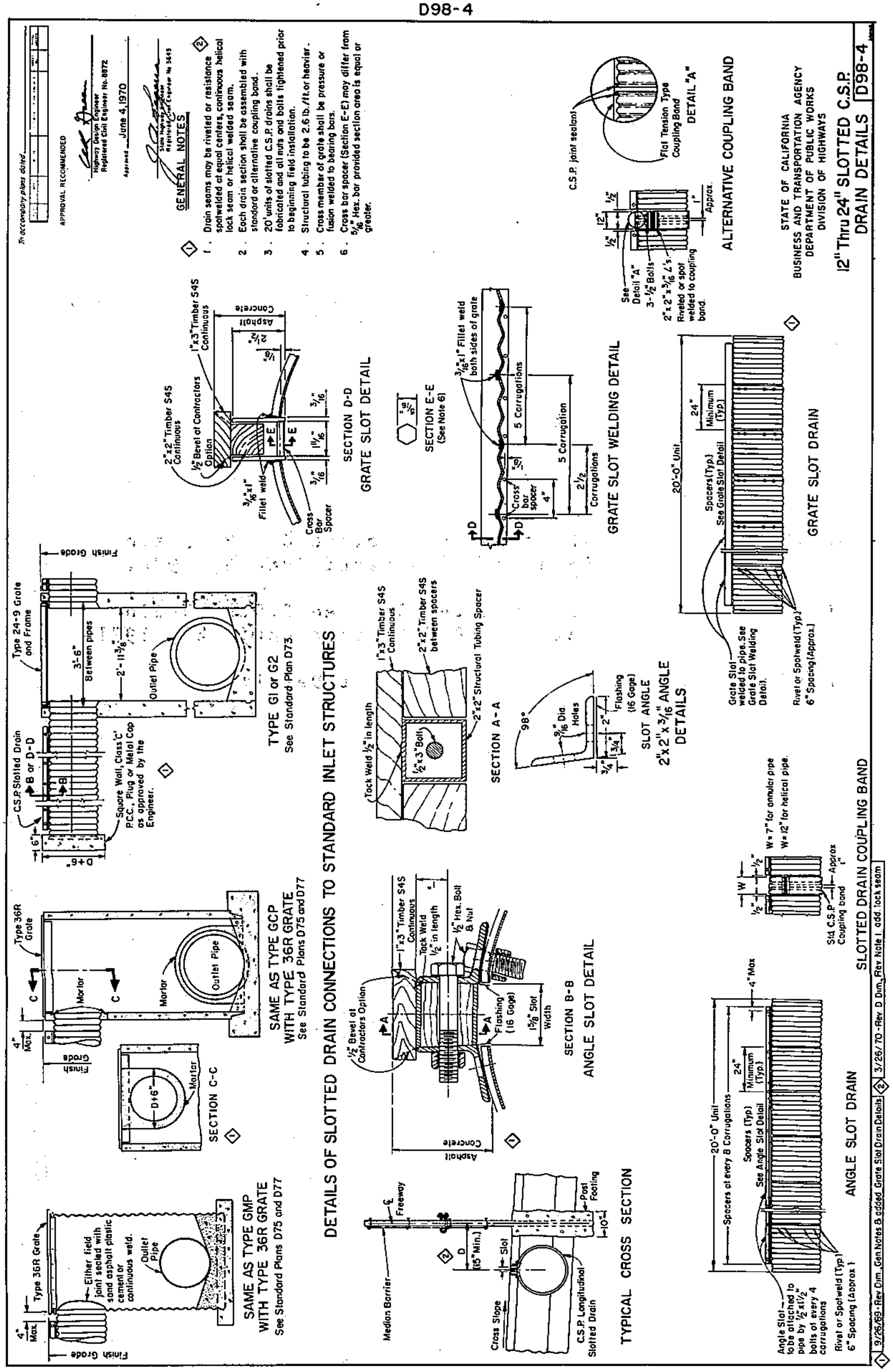
FIGURE 16

REFERENCE

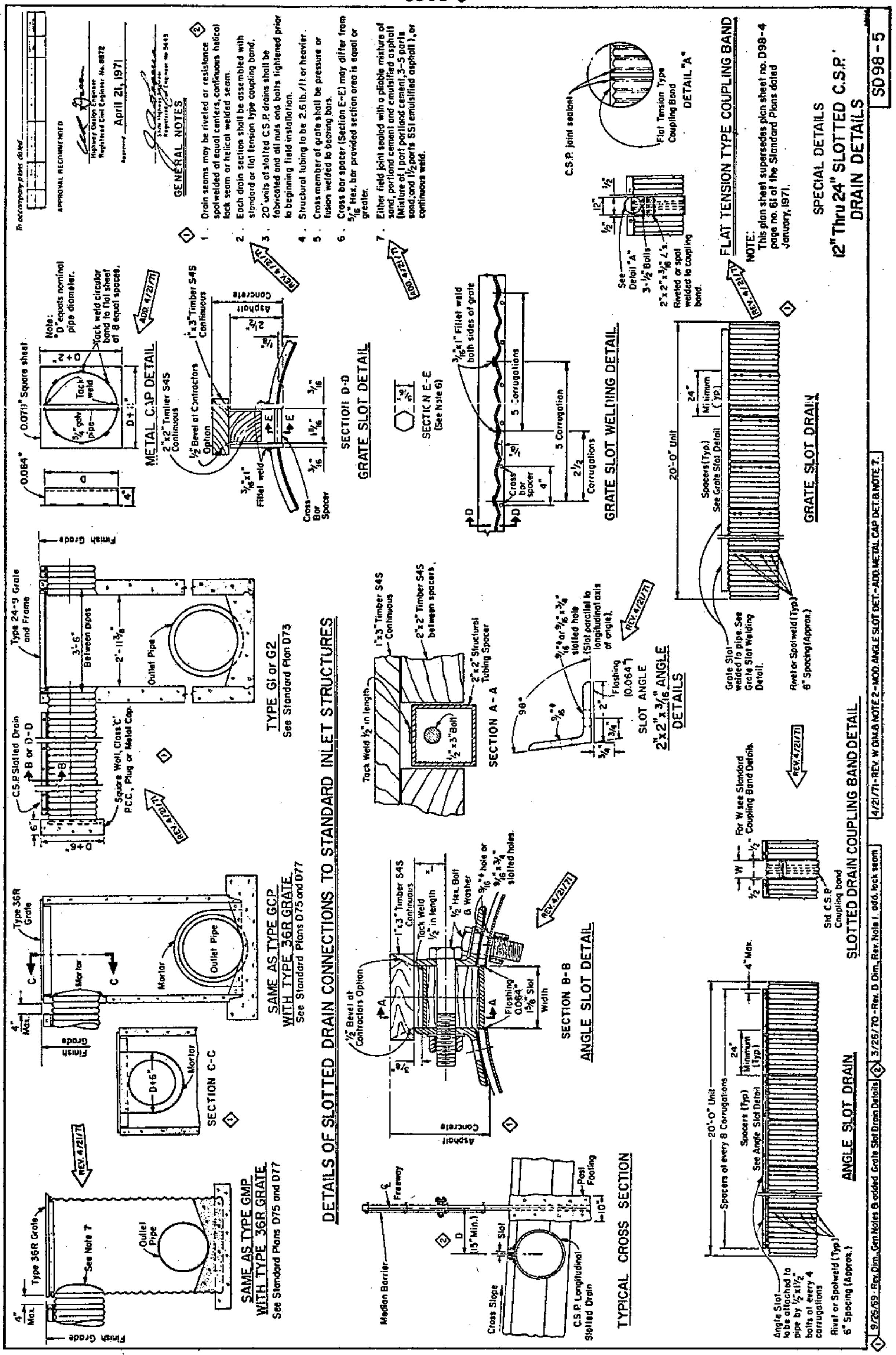
1. "Investigation of the Destructive Effect of Flotation Tires on Flexible Pavements", E. Zube and R. Forsyth, January 1965.

APPENDIX

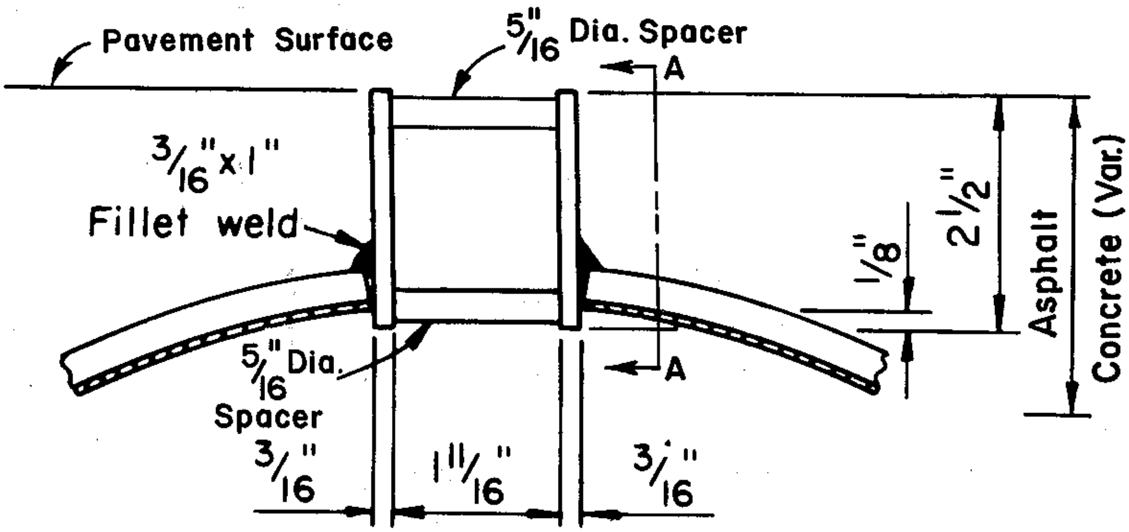
DRAWING NO. 1	12" thru 24" Slotted C.S.P. Drain Details D98-4 dated June 4, 1970.
DRAWING NO. 2	12" thru 24" Slotted C.S.P. Drain Details SD98-5 dated April 21, 1971.
DRAWING NO. 3	Special Grate Slot Detail


DETAILS OF SLOTTED DRAIN CONNECTIONS TO STANDARD INLET STRUCTURES
SAME AS TYPE GMP WITH TYPE 36R GRATE
See Standard Plans D75 and D77
SAME AS TYPE GCP WITH TYPE 36R GRATE
See Standard Plans D75 and D77
SECTION C-C
TYPE G1 or G2
See Standard Plan D73
TYPICAL CROSS SECTION
SECTION B-B
ANGLE SLOT DETAIL
SECTION A-A
SLOT ANGLE 2"x2"x3/16" ANGLE DETAILS
SECTION D-D
GRATE SLOT DETAIL
SECTION E-E (See Note 6)
GRATE SLOT WELDING DETAIL
ANGLE SLOT DRAIN
SLOTTED DRAIN COUPLING BAND
GRATE SLOT DRAIN
ALTERNATIVE COUPLING BAND
DETAIL "A"
GENERAL NOTES
1. Drain seams may be riveted or resistance spotwelded at equal centers, continuous helical lock seam or helical welded seam.
2. Each drain section shall be assembled with standard or alternative coupling band.
3. 20' units of slotted C.S.P. drains shall be fabricated and all nuts and bolts tightened prior to beginning field installation.
4. Structural tubing to be 2.6 lb./ft. or heavier.
5. Cross member of grate shall be pressure or fusion welded to bearing bars.
6. Cross bar spacer (Section E-E) may differ from 5/16" Hex. bar provided section area is equal or greater.
APPROVAL RECOMMENDED
Highway Design Engineer
June 4, 1970
STATE OF CALIFORNIA
BUSINESS AND TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
12" Thru 24" SLOTTED C.S.P. DRAIN DETAILS
D98-4
9/26/69 - Rev. Dim., Gen Notes & added Grate Slot Drain Details
3/26/70 - Rev. D Dim., Rev Note 1, add lock seam

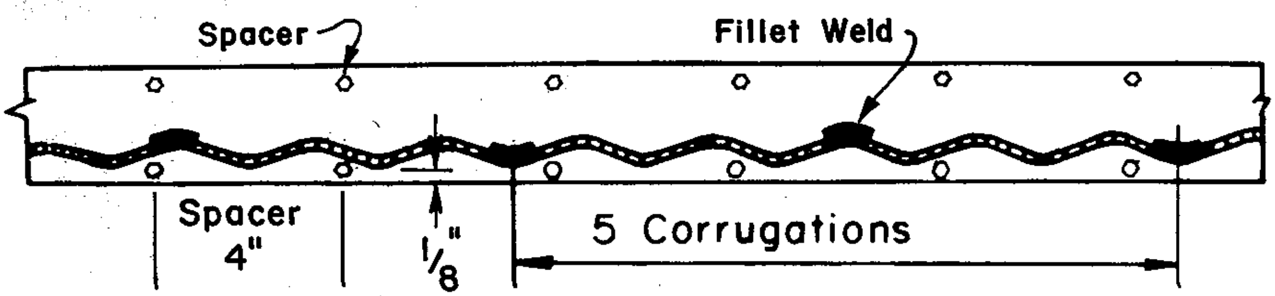
DRAWING NO. 1


DETAILS OF SLOTTED DRAIN CONNECTIONS TO STANDARD INLET STRUCTURES
SAME AS TYPE GMP WITH TYPE 36R GRATE
SAME AS TYPE GCP WITH TYPE 36R GRATE
TYPE G1 or G2
SECTION C-C
TYPICAL CROSS SECTION
SECTION B-B
ANGLE SLOT DETAIL
SECTION A-A
2"x2"x3/16" ANGLE DETAILS
ANGLE SLOT DRAIN
SLOTTED DRAIN COUPLING BAND DETAIL
METAL CAP DETAIL
SECTION D-D
GRATE SLOT DETAIL
SECTION E-E
GRATE SLOT WELDING DETAIL
GRATE SLOT DRAIN
GENERAL NOTES
FLAT TENSION TYPE COUPLING BAND
DETAIL "A"
SPECIAL DETAILS
12" Thru 24" SLOTTED C.S.P. DRAIN DETAILS
SD98-5

DRAWING NO. 2



SPECIAL GRATE SLOT DETAIL



SECTION A-A

DRAWING NO. 3